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Medical Geology: A Globally Emerging Discipline

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ABSTRACT
Medical geology is an emerging discipline that, broadly defined, examines the public health impacts of geologic materials and geologic processes. Medical Geology, the study of the impacts of geologic materials and processes on animal and human health, is a dynamic emerging discipline bringing together the geosciences, biomedical, and public health communities to solve a wide range of environmental health problems. Among the Medical Geology described in this review are examples of both deficiency and toxicity of trace element exposure. Goiter is a widespread and potentially serious health problem caused by deficiency of iodine. In many locations the deficiency is attributable to low concentrations of iodine in the bedrock. Similarly, deficiency of selenium in the soil has been cited as the principal cause of juvenile cardiomyopathy and muscular abnormalities. Overexposure to arsenic is one of the most widespread Medical Geology problems affecting more than one hundred million people in Bangladesh, India, China, Europe, Africa and North and South America. The arsenic exposure is primarily due to naturally high levels in groundwater but combustion of mineralized coal has also caused arsenic poisoning. Dental and skeletal fluorosis also impacts the health of millions of people around the world and, like arsenic, is due to naturally high concentrations in drinking water and, to a lesser extent, coal combustion. Other Medical Geology issues described include geophagia, the deliberate ingestion of soil, exposure to radon, and ingestion of high concentrations of organic compounds in drinking water. Geosciences and biomedical/public health researchers are teaming to help mitigate these health problems.

Key words: *Medical Geology, Environmental Health, Geophagia, Human health*

1. INTRODUCTION

Medical geology is an emerging discipline that, broadly defined, examines the public health impacts of geologic materials and geologic processes. The scope and range of medical geology include: (1) identifying and characterizing natural and anthropogenic sources of harmful materials in the environment; (2) learning how to predict the movement and alteration of chemical, infectious, and other disease-causing agents over time and space; and (3) understanding how people are exposed to such materials and what can be done to minimize or prevent such exposure. 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. While the juxtaposition of the terms may be new, medical geology is really a re-emerging field. Thousands of years ago, Hippocrates and Aristotle noted relationships between environmental factors and the distribution of various diseases. In ancient China and India, minerals were understood to have healing as well as potentially deleterious properties. But the 20th century celebrated reductionist science, and now the term ‘‘medical geology’’ strikes many as novel. The definition of medical geology as the scientific discipline that examines the impacts that geologic materials and processes have on human and ecosystem health includes both natural and anthropogenic sources of potential health problems, and implies that wildlife and plant diseases are included. In contrast to the emphasis on treatment and cure that the term ‘‘medical’’ implies, work in this field is more accurately described as ‘‘public health’’ because of its focus on prevention. The consensus reached at a recent conference was that linguistic precision should be compromised in favor of a less burdensome and complex term than proposed alternates. The most accurately descriptive term for this field of research, hydro, biogeo, chemo, epidemio, pathoecology will not be used for obvious reasons. The working group, Medical Geology: Earth Systems, Resource Use and Human Health, was convened in Washington,

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DC on June 7-8, 2002 at the Healthy Ecosystems/Healthy People conference sponsored by the International Society for Ecosystem Health (ISEH). The working group agreed to continue using the term ‘‘medical geology,’’ recognizing that the more important issue is to emphasize the broad definition as stated above. While ‘‘medical geology’’ is less than perfect to describe this discipline, it is easy to use and remember, and is accessible to policy-makers and the public-two groups identified as critical in outreach and promotion activities.

Among the environmental health problems that geologists and the medical community need to collaborate on include: exposure to natural dust and to radioactivity; exposure to toxic levels of trace essential and non-essential elements such as arsenic and mercury; nutrient trace element deficiencies; naturally occurring toxic organic and inorganic compounds in drinking water; identification and affects of volcanic emissions, etc. Geoscientists have also developed an array of tools and databases that can be used by the environmental health community to study vector-borne diseases, to model the dispersion of pollutants in surface and ground water and in the air, and can be applied to occupational health problems resulting from exposure to minerals.

1.1 NATURALLY OCCURRING DUSTS

Exposure to mineral dust can cause a wide range of respiratory problems. The dust can be generated by mining rocks or coal, sandblasting, and smoke plumes from fires (both natural and man-made) or simply from the wind dispersing fine-grained minerals from the earth’s surface. Asbestos is a diverse group of minerals with several common properties; separation into long thin fibers, heat resistance, and chemically inertness. In the 1980s the U.S. medical community recognized that exposure to respirable asbestos fibers can cause severe health problems including mesothelioma, lung cancer, and asbestosis. Hence, many commercial asbestos mines 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, has caused significant health problems in the mining community of Libby, Montana, USA [1]. Lung abnormalities (such as pleural thickening or scarring) occurred in about 18 percent of the adults tested.

1.2. *Trace element exposure: Deficiency and toxicity*

Trace elements play an essential role in the normal metabolism and physiological functions of animals and humans. Some 22 such elements are known or thought to be “essential” for humans and other animals. “Macronutrients” are required in fairly large amounts (e.g., grams per kilogram of diet), whereas “micronutrients” are required in much smaller amounts (e.g., microgram-to milligrams per kilogram of diet). Sixteen elements are established as being essential for good health. Calcium, phosphorus, magnesium, and fluoride for example, are required for structural functions in bone and membranes. Sodium, potassium, and chloride are required for the maintenance of water and electrolyte balance in cells. Zinc, copper, selenium, manganese, and molybdenum are essential constituents of enzymes or serve as carriers (iron) for ligands essential in metabolism. Chemical elements are also important in the functioning of the endocrine system. For instance, iodine is an essential component of the thyroid hormone thyroxine, and chromium is the central atom of the hormone-like glucose tolerance factor. Because these are all critical life functions, the tissue levels of many “nutritionally essential elements” tend to be regulated within certain ranges, and dependent on several physiological processes, especially 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 excess of trace elements. Food is a major source of trace elements in humans and animals. 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 are known for iodine, copper, zinc, selenium, molybdenum, manganese, iron, calcium, arsenic, and cadmium [2]. Endemic diseases correlative with soil deficiencies in selenium and iodine have been described in at least two general cases, the juvenile cardiomyopathy “Keshan Disease” [3] and the iodine deficiency disorders including goiter and myxedematous cretinism [4] respectively. In the following paragraphs, examples of adverse health affects due to trace element deficiencies and excesses are described. Chronic exposure to non-essential elements such as arsenic is also described.

2. DISEASES DUE TO TRACE ELEMENT DEFICIENCIES

2.1 Iodine

The connection between geologic materials and trace element deficiency is well documented 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. In ancient China, Greece and Egypt as well as among the Incas, people affected by goiter, were given seaweed to provide the needed iodine [5]. 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.

2.2 Selenium

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 (Kashin-Beck disease). In the 1960s scientists suspected that these diseases were of geological origin, and in the 1970s the probable solution was found. These diseases were always located in areas with low selenium soils [3]. The use of dietary selenium in the prevention and treatment of these diseases has been a great success. The occurrence of low selenium is thought to contribute to other illnesses including impaired reproduction, various cancers, infectious diseases, and, due to its antioxidant properties, rapid aging. Also, metabolic selenium combined with other trace elements appears to promote good health. For example, the ratio of selenium to arsenic in the body can modulate the toxic effects of either element alone [6]. The effects of Se intake on as methylation have only been recently studied in epidemiologic studies of As exposed individuals [7].

3. TOXICITY OF ESSENTIAL AND NON-ESSENTIAL ELEMENTS

3.1 Arsenic

Arsenic and arsenic compounds are human carcinogens [8]. Exposure to arsenic may occur through several anthropogenic sources, including mining, pesticides, pharmaceuticals, glass and microelectronics, and most commonly, natural sources. Exposure to arsenic occurs via ingestion, inhalation, dermal contact and the parenteral route to some extent. Drinking water contaminated with arsenic is 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 the drinking water is contaminated with high concentrations of arsenic. General health effects 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 cancers. Significantly higher standardized mortality rates and cumulative mortality rates for cancers of the skin, lung, liver, urinary bladder, kidney, and colon occur in many areas polluted with arsenic [9-11].

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, the arsenic might be desorbed and dissolved from iron oxide minerals by anerobic (oxygen-deficient) groundwater, or it might be derived from the dissolution of arsenic-bearing sulfide minerals such as pyrite by oxygenated waters [13]. Understanding the mechanisms by which arsenic is mobilized will permit the public health officials around the world to identify aquifers that may pose a threat to their communities.

Undetectable in its early stages, arsenic poisoning takes between 8 and 14 years to impact on health, depending on the amount of arsenic ingested, nutritional status, and immune response of the individual. Arsenic is toxic substance to human health and toxicity depends on the amount of arsenic intake, which is classified into acute, sub-acute and chronic toxicity respectively. It is a silent killer. It is 4 times as poisonous as mercury and its lethal dose (LD) for human is 125 milligram. Drinking water contamination causes the last variety of toxicity. Inhalation, ingestion and skin contact are the primary routes of human exposure to the arsenic. Chronic arsenic ingestion from drinking water is known to cause skin cancer, and there is substantial evidence that it increases risk for cancers of the bladder, lung, kidney, liver, colon, and prostate. Recent studies have also shown that arsenic is associated with a number of non-neoplastic diseases, including cardiac disease, cerebrovascular disease, pulmonary disease, diabetes mellitus and diseases of the arteries, arterioles, and capillaries [14]. Individuals with chronic Hepatitis B infection, protein deficiency or malnutrition may be more sensitive to the effects of arsenic[15]. Children and older adults may be other groups at special risk. Observable symptom to the arsenic poisoning can be thickening and discoloration of skin, stomach pain, nausea, vomiting, diarrhea, numbness in hand and feet, partial paralysis, blindness.(Fig:1,2,3). Arsenic toxicity is dose dependent, and particularly on the rate of ingestion of arsenic compounds and their excretion from the body but it also accumulate into the body and passes slowly out through hair and nail. Most of the ingested arsenic is excreted from the body through urine, stool, skin, hair, nail and breath. In excessive intake, some amount of arsenic is accumulated in tissues and inhibits cellular enzyme activities.

The worst affected people in Bangladesh are poor women and children. In poor rural households, it is the adult female who is the generally the most undernourished and most vulnerable to disease. When the husband discovers symptoms of arsenicosis on her body, he often refuses to keep her under the same roof. If the woman is fortunate, the husband simply sends her back to her parents for treatment. In most case, however, the husband finds it too risky to maintain the marital relationship and seeks divorce. Women are unable to get married and wives have been abandoned by their husband. As a result, the divorced women find no place in the society and, with their children, become destitute. In villages, it becomes a problem for parents to get their affected daughters married. Arsenicosis also affects the productivity of victims who are often so incapacitated that they are unable to work and become liabilities for their families. The children of the poor have been drinking contaminated water since their birth. They, too, may eventually suffer arsenicosis. It will be very difficult, perhaps impossible, for the parents of an affected young woman to find a groom for her without offering a huge dowry. The provision of dowry is already a difficult, social problem, but will be further compounded by the arsenic problem.

3.2 Fluoride

Over-exposure to trace elements in geologic materials is responsible for toxicity effects in humans and animals. One of the most studied trace elements in this regard is fluorine. The fluoride ion (F-) stimulates bone formation and also reduces dental caries at doses of at least 0.7 mg/L in drinking water. However, excess fluoride (>1 mg/L) exposure can cause fluorosis of the enamel (mottling of the teeth) and bone (skeletal fluorosis) [14]

Figure 1. Signs of Arsenicosis: spots on the hands.

Figure 2. Squamous cell carcinoma on heel. The patient was from the village of Singergdanga (police station Gaighata), North 24-Paraganas District.

Figure 3. Hyperkeratosis on sole. The patient died of lung cancer. The patient was from the village of Chandpur North 24-Paraganas District.

3.2.1 Dental Fluorosis:

Generally ingestion of water having a fluoride concentration above 1.5 – 2.0 mg/l may lead to dental mottling, an early sign of dental fluorosis which is characterized by opaque white patches on teeth. In advanced stages of dental fluorosis, teeth display brown to black staining followed by pitting of teeth surfaces. Dental fluorosis produced considerable added dental costs (tooth deterioration) and significant physiological stress for affected population. Dental fluorosis is endemic in 14 states and 1, 50,000 villages in India. The problems are most pronounced in the states of A.P., Bihar, Gujarat, M.P., Punjab, Rajasthan, Tamil Nadu and Uttar Pradesh Types of mottling are shown in Figure: 4.

3.2.2 Skeletal Fluorosis:

Skeletal fluorosis may occur when fluoride concentrations in drinking water exceed 4-8 mg/l, which leads to increase in bone density, calcification of ligaments rheumatic or arthritic pain in joints and muscles along with stiffness and rigidity of the joints, bending of the vertebral column and excessive bone formation or osteosclerosis, a basis symptom of skeletal fluorosis [17]; [18]. Crippling skeletal fluorosis can

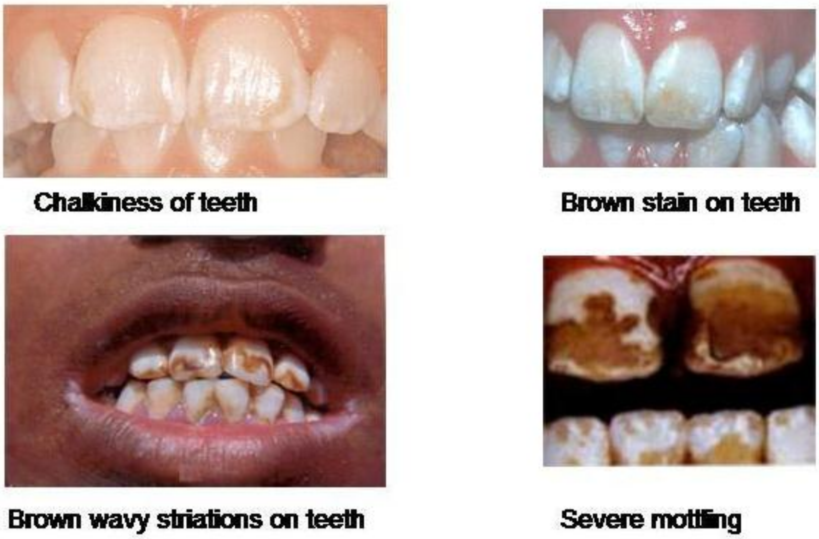

Figure 4. Types of Mottling

Figure 5. Extent of Skeletal Fluorosis

occur when a water supply contains more than 10 mg/l [19] is shown in Figure-5.

3.3 Nitrates as a health hazard

In India, high concentration of groundwater nitrate (more than 45 ppm) have been found in many districts of Andhra Pradesh, Bihar, Delhi, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Tamilnadu, Rajasthan, West Bengal and Uttar Pradesh [20]. The highest groundwater nitrate concentration of 3080 ppm was found in Bikaner in Rajasthan [21]. The study carried out by (A.G.S Reddy et al., 2007) in Anantapur district revealed that 65% of samples have shown nitrate levels above the desirable limit (45 ppm). Sources of nitrate in groundwater can be considered in four categories: (1) Natural sources (2) waste materials (3) irrigated agriculture and (4) row crop agriculture. The major sources include intensive animal operations with nitrate from over application of animal wastes, and irrigated and row crop agriculture, with nitrate from fertilizer-induced mineralization of soil organic nitrogen and from over application. Septic tank system and other sources, such as landfills can be concern in localized areas [22]. High concentration of nitrate in the drinking water causes many serious health problems especially in children and young livestock. Due to its hazardous nature, the permissible limit of nitrate for drinking water has been reduced from 100 mg/l to 45 mg/l by the Bureau of Indian standards in recent years. Although methemoglobinemia (blue-baby syndrome) is the most immediate life threatening effect of the nitrate exposure, there are a number of equally serious long terms, chronic impacts. In numerous studies, exposure of high levels of nitrate in the drinking water has been linked to a variety of effects ranging from enlargement of the thyroid to 15 types of cancer and two kinds of birth defects and even hypertension [23]. Research shows a definite relationship between increasing rates of stomach cancer with increasing nitrate intake [24]. Through the effect of continuous consumption of high nitrate in water may not physically visible as in the case of fluoride, the local people have complained of recurring indigestion and gastrointestinal problems in the south eastern part of Anantapur district, Andhra Pradesh, India.

3.4 Other Medical Geology Issues

3.4.1 Geophagia

Geophagia (or geophagy) is also an area of concern in medical geology. 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 a built-in response to nutritional deficiencies resulting from a poor diet. Geophagy is attaining renewed and serious interest within the scientific research community.

3.4.2 Radon

Exposure to natural gases such as radon is potentially hazardous. Geologic materials are the most important factor controlling the source and distribution of radon. Relatively high levels of radon emissions are associated with specific types of bedrock and unconsolidated deposits, including some 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 [25]. 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 (Appleton, 2005). Radon that enters poorly ventilated buildings, caves, mines, and tunnels can reach dangerously high concentrations.

3.4.3 Asbestos

Asbestos is the name for a group of naturally occurring silicate minerals that can be separated into fibres. The fibres are strong, durable, and resistant to heat and fire. There are several types of asbestos fibres, of which three have been used for commercial applications: Chrysotile, or white asbestos, comes mainly from Canada, and has been very widely used in the U.S. It is white-gray in colour and found in serpentine rock. Amosite, or brown asbestos, comes from southern Africa. Crocidolite, or blue asbestos, comes from southern Africa and Australia. We selected “asbestos” as a whole, since it has been studied as a key mineral for its properties as a dangerous fibrous silicates. Dusts from other silicates show similar occupational health impacts, but have not achieved the notoriety of asbestos. Asbestos mining internationally has been found to create occupational health risks for miners and mineworkers in related processing industries. The earliest data on the hazards of asbestos came from mine workers in the extraction process, but gradually it became clear that workers in all asbestos-using industries also showed signs of health impacts. The majority of studies focus on asbestos as a hazardous mined product and safety issues relate to exposure through breathing in asbestos particles in and around the mines. The most severe occupational exposure is that with the greatest contact with the asbestos particles in respirable form. Along with coal and other silicate dusts, the dangers of asbestos mining relate largely to damage to respiratory function and lungs.

3.4.4 Uranium

Uranium mining has a long history, but most scientists recognize that it is only for the last 30 years that the health effects of occupational exposures to radiation in mines has been discussed fully. Many of the studies focus around lung cancer, the risks of which are only now being evaluated more fully. This type of radiation-induced occupational cancer now appears to be one of the most important radiation injuries known to occur among workers occupationally exposed to ionizing radiation. Uranium mining creates risks in 2 ways, through dusts and through released radon - a radioactive gas of natural origin. Radon’s principal isotope is radon-222, stemming from uranium-238 present at various concentrations in all soils. Radon is found everywhere in the earth's atmosphere but has low reactivity by itself. However in the process of mining, dusts get inhaled by miners. For example, as one study reports on East German Uranium mines, in some mines in the past there was drilling with air floating and a lack of forced ventilation. Dust levels were very high and there was a significant inhalative incorporation of alpha- radiating substances, mostly from short-lived radon progeny. However, long-lived alpha-radiating substances such as uranium-238 contributed considerably to the radiation dose” [26] Radon particulate daughters are responsible for alpha irradiation of the bronchial epithelium. Epidemiological studies on miners indicate that radon exposure causes an increased risk of lung cancer in these workers but “how much?” and “how?” is still under investigation.

4. CONCLUSION

The objectives of Medical Geology are to identify harmful geologic agents, determine the conditions of exposure that promote deteriorating health conditions, and develop sound principles, strategies, programs and approaches necessary to eliminate or minimize health risks. Interaction and communication is necessary between the geosciences, biomedical, and public health communities to protect human health from the damaging effects of physical, chemical and biological agents in the environment. We recommend that Medical geology be included in higher education curricula so that students will be aware of the connection between geology and health and encouraged to pursue a career in Medical Geology. The rapidly emerging scientific discipline of Medical Geology holds promise for increasing our environmental health knowledge base, and contributing to substantial tangible improvements in the well-being of the global community. An important task is to foster acceptance of the subdiscipline medical geology. This may facilitate support for research by raising awareness among funding agencies and decision-makers. The general public must be educated on the value of this field, not only for its promise of finding practical, effective solutions to serious public health problems, but because people can encourage their elected leaders to champion this important cause. Given the philosophy and goals of the ISEH, a liaison between the Society and the IUGS Medical Geology Initiative would likely benefit both Organizations. These complementary communities together can forge a strong, self-sustaining interdisciplinary scientific discipline-Medical Geology.

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