Medical Geology: an emerging speciality

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Background

> *"Whoever wishes to investigate medicine properly, should proceed thus … We must also consider the qualities of the waters, for as they differ from one another in taste and weight, so also do they differ much in their quality" (Hippocrates, 460 – 377 BC).*

The quotation from the works of Hippocrates, a Greek physician of the Classical Period, shows that a belief that health and 'place' are causally related is of ancient origin. Knowledge of specific animal diseases also originated long ago. Even in Chinese medical texts of the third century BC relationships are found. However most of such observations were lost because they were not written down. As the science grew, many of the previously unknown relations of causes began to be understood and a new scientific field emerged: Medical Geology. Understanding the role of rocks, soil and groundwater in controlling the health of humans and animals requires the collaboration of geochemists, mineralogists and medical researchers.

Medical Geology is defined as the science dealing with the relationship between natural geological factors and health in man and animals, and understanding the influence of ordinary environmental factors on the geographical distribution of such health problems. Medical Geology is therefore a broad and complicated subject which requires interdisciplinary contributions from different scientific fields if the problems are to be understood, mitigated or resolved.

One of the oldest documentations of Medical Geology was provided by Marco Polo, who left Venice with his father and uncle in 1271 to travel to China. In 1275 they arrived to the summer residence of Kublai Khan. Marco Polo was then employed by the emperor and worked as his emissary and was even for a time governor of a part of China.

> *"At the end of the ten days he reaches a province called Su-chau … Travelers passing this way do not venture to go among these mountains with any beast except those of country, because a poisonous herb grows here, which makes beasts that feed on it lose their hoofs; but beasts born in the country recognize this herb and avoid it."*

Marco Polo thus reported that he could only use local horses in the mountainous areas of China, and not his European horses. The imported horses died because they could not avoid these poisonous plants. He also described the symptoms. He did not know that his reports were of geomedical origin. However we now believe that the areas he described contain high natural contents of selenium and the symptoms of the sick animals show that they were affected by selenium poisoning.

Modern interest can be traced to the 19th century and the realization that tiny amounts of many inorganic elements are necessary for good health in humans and other mammals yet may be injurious in excess. One of the first connections was that of environmental iodine and human goiter and cretinism: environments remote from oceans have too little iodine in soil and water and, worse, goitrogenic substances can exacerbate matters. In the first half of the 20th century the link between fluoride in drinking water and dental caries protection was recognized, leading to artificial fluoridation of water supplies in many areas. Selenium toxicity in horses was described in the USA and Ireland and, subsequently, the link between low environmental selenium and cardiomyopathy in sheep has stimulated work on the protective action of Se in human health: Se supplementation is now one of the most common forms of protective self-medication. The 19th century tonic 'Fowler's Solution' contained As and excessive ingestion caused skin lesions and cancer: now we recognize Blackfoot disease in Taiwan and epidemic As poisoning in Bangladesh, both from As contaminated drinking water. In the mid 20th century Itai-itai disease in Japan was linked to Cd pollution of food and water while methyl mercury poisoning in Japan became notorious as Minamata disease. It was soon ascertained that microorganisms and dissolved organic matter could change Hg to the lipid-soluble methyl-Hg which concentrates up the food chain. Fish mercury advisories are now prevalent in the USA. In the 1960s lead was recognized as more than an industrial poison and Pb in air, water and dust was shown to injure young children, especially their nervous systems. Advanced countries soon banned the use of Pb in paints, cans and petrol. In the 20th century many map studies were published (medical geography) linking disease distribution to rock or soil type.

Effects of geology

Our planet Earth is the ultimate source of all metals. Metals are ubiquitous in the lithosphere where they are inhomogenously distributed and occur in different chemical forms. Ore deposits are thus merely natural concentrations which are commercially exploitable. While such anomalous accumulations are the focus of mineral exploration the background concentrations of metals which occur in common rocks, sediments and soils are of greater significance to the total metal loading in the environment. All known elements are present at some level of concentration throughout the natural environment, in humans, animals, vegetables and minerals, and their beneficial and harmful effects have been present since evolution began.

Geology may appear far removed from human health. However, rocks are the fundamental building blocks of the planet surface and different rock mineral assemblages contain the 92 naturally occurring chemical elements found on Earth. Many elements are essential to plant, animal and human health in small doses. Most of these elements are taken into the human body via food and water in the diet and in the air we breathe. Through physical and chemical weathering processes, rocks break down to form the soils on which the crops and animals that constitute the food supply are raised. Drinking water travels through rocks and soils as part of the hydrological cycle and much of the dust and some of the gases contained in the atmosphere are of geological origin. Hence, through the food chain and through the inhalation of atmospheric dusts and gases, there are direct links between geochemistry and health.

We need to understand the nature and magnitude of these geological sources for developing approaches to assessing the risk posed by metals in the environment. It is very important to be able to distinguish between natural and anthropogenic contributions to metal loading. Table 1 shows the significant differences between different rock types and their content of heavy metals. Concentrations of metals can range over orders of magnitude among different types of rocks. For example the concentrations of elements such as nickel and chromium are much higher in basalts than in granites whereas the reverse is true for lead. These types of bedrock are also easily weathered and the elements will be mobilized into the environment. In sediments the heavy metals tend to be concentrated in the fractions with the finest grain size and the highest content of organic matter. Black shales, for example, tend to be enriched in these elements.

Volcanism and related activities are the principal processes which bring metals to the surface from deep in the earth. As an example, the volcano Pinatubo ejected about 10 billion tonnes of magma and 20 million tonnes of SO_2 over just two days in June 1991 and the resulting aerosols influenced the global climate for three years. This event alone introduced two million tonnes of zinc, one million tonnes of copper and 5,500 tonnes of cadmium to the surface environment. In addition to this, 100,000 tonnes of lead, 30,000 tons of nickel, 550,000 tonnes of chromium and 800 tonnes of mercury. Volcanic eruptions redistribute those elements which under certain conditions are regarded as harmful, such as arsenic, beryllium, cadmium, mercury, lead, radon and uranium, plus the remaining 72 elements, many

Figure 1 – Volcanic eruption at Krafla, Iceland 1980. Photo Olle Selinus

Table 1 – Average abundance of selected elements in bedrock (all values in ppm)

Element	Earth's crust	Ultrabasic	Basalt	Granite	Shale	Limestone
As	1.8	1	2	1.5	15	2.5
Cd	0.2	–	0.2	0.2	0.2	0.1
Co	25	150	50	1	20	4
Cr	100	2,000	200	4	100	10
Cu	55	10	100	10	50	15
Pb	12.5	0.1	15	20	20	8
Se	0.05	–	0.05	0.05	0.6	0.08
U	2.7	0.001	0.6	4.8	4	2
W	1.5	0.5	1	2	2	0.5
Zn	70	50	100	40	100	25

of which have still undetermined biological effects. It is also important to realize that there are on an average 60 subaerial volcanoes erupting on the surface of the earth at any given time (Fig. 1), releasing metals to the environment. Submarine volcanism is even more significant than that at continental margins and it has been conservatively estimated that there are at least 3,000 vent fields on the mid ocean ridges. One interesting fact is that about 50% of the deposition of SO_2 is natural deposition mainly from volcanoes, and only 50% is from human sources.

Also, radon is a consequence of geological activity. Important parts of the bedrock have elevated uranium contents including for example alum shales and certain granites and pegmatites. Radon derived from natural radioactive sources is acknowledged as a public health hazard problem. The number of radon-related cases of lung cancer is increasingly qualifying radon to be the major radiation problem with respect to health in several countries. More recently, focus has been put on radon in domestic water as a potential radiation protection problem. The radon content of water also has a direct link to local geological conditions. Many types of rock have elevated uranium contents. These include for example alum shales, certain granites, and pegmatites. The number of radon-related cases of lung cancer is increasing and qualifying radon to be the major radiation problem with respect to health in several countries. Some current building practices, such as the use of light concrete made from uranium-rich alum shale, and a reduction in building air circulation (justified from energy conservation aspects) have in many cases aggravated the problem. Previous risk assessments have focused on radon emanating from the domestic use of water as an additional source of radon in indoor air. Recent studies suggest that the intake of radon-rich water should be considered a risk as such, especially for critical groups such as infants.

Elements are both necessary and toxic

Paracelsus (1493-1541) defined the basic law of toxicology. "All substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy." This relation between the dose and effect for any substance is shown by the curve starting at zero (dashed line) in Figure 2. Increase of the amount/concentration (on the horizontal axis) causes increasing negative biological effects (on the vertical axis), which may lead to inhibition of biological functions, eventually to death. Evidently, decreasing concentrations of *non-essential* elements/substances are beneficial. The situation for *essential* elements is different. Negative biological effects increase both for increasing and decreasing concentrations, illustrated by the continuous curve in the form of a trough in Figure 2. That may lead to inhibition of life functions in both cases. Thus, too much or too little are equally harmful.

All elements are present in nature itself. Most of them are essential. But which are those elements essential for humans and animals? Major elements essential for human and animal life are for example calcium, chlorine, magnesium, phosphorus, potassium, sodium and sulfur.

Essential trace elements in low concentrations for human and animal life are for example chromium, cobalt, copper, fluorine, iodine, iron, manganese, molybdenum, selenium and zinc. However, elements with probably no recognized biological role are called non-essential elements, often with harmful properties, e.g., cadmium, arsenic, mercury and lead.

Several elements are frequently involved in environmental toxicity problems, for example arsenic, boron, chromium, copper, fluorine, molybdenum, nickel and zinc. Although it is not possible to quantify the hazards and deleterious effects associated with the trace elements in common use, some elements clearly present a more serious problem than others, for example lead, mercury and cadmium which are in a class by themselves and have received attention from scientists.

It is necessary to determine how much "contamination" merely reflects the preexisting natural background level. This question of natural background levels has important economic implications. Human activities of all kinds have led to metals being redistributed from sites where they are fairly harmless to places where they affect humans and animals in a negative way. This is especially serious since acid rain and associated acidification accelerates this process so as to make some heavy metals, e.g. mercury, easily accessible and thus absorbed in the nutritional chain and essential trace elements, such as selenium, become unavailable to living organisms. The 92 naturally occurring elements are not distributed evenly across the surface of the earth and problems can arise when element abundances are too low (deficiency) or too high (toxicity). The inability of the environment to provide the correct mineral balance can lead to serious health problems. The links between environment and health are particularly important for subsistence populations who are heavily dependent on the local environment for their food supply. Approximately 25 of the naturally occurring elements are known to be essential to plant and animal life in trace amounts, these include, Ca, Mg, Fe, Co, Cu, Zn, P, N, S, Se, I and Mo. On the other hand, an over-abundance of these elements can cause toxicity problems. Some elements such as As, Cd, Pb, Hg and Al have no/limited biological function and are generally toxic to humans (Table 2).

Most elements are known as trace elements because their natural abundances on Earth are generally very low (mg/kg concentrations in most soils). Trace element deficiencies in crops and animals are therefore commonplace over large areas of the world and mineral supplementation programs are widely practiced in agriculture. Trace element deficiencies generally lead to poor crop and animal growth, poor yields, and to reproductive disorders in animals. These problems often have the greatest impact on poor populations who can least afford mineral interventions for their animals.

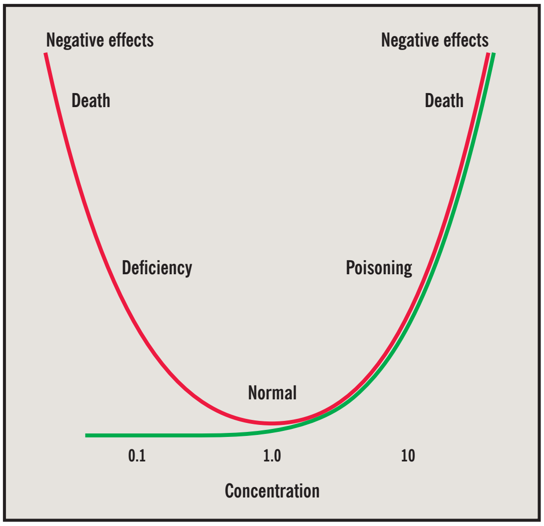

Figure 2 – Dose-effect curve showing the relationship between concentrations and biological effects of essential (red line) and of non-essential (green line) elements

The presence of toxic elements in soil or rocks, whether due to natural geochemistry or human activities, including pollution, usually influences human health, indirectly ingested via food or drinking water (Fig. 3). Although many places in the world rely solely on locally produced food, food consumption in modern industrialized societies is much more diverse, including food produced in different geographical areas. Drinking water, however, is usually obtained locally and therefore strongly related to local geochemistry. Problems of excess intake from drinking water have been encountered for several inorganic compounds, including fluoride in Africa and India, arsenic in certain areas of Argentina, Chile, and Taiwan; selenium in seleniferous areas in the U.S., Venezuela, and China; and nitrate in agricultural areas with heavy use of fertilizers.

Heavy metals are not the only elements that are addressed by the subject of Medical Geology. Classic internationally recognized examples of diseases related to geological factors are goiter (which is due to iodine deficiency), and those diseases caused by excess or deficiency of certain elements such as fluorine or selenium. Cardiovascular mortality and morbidity in relation to water hardness which is controlled by its geological settings is also one potential subject of research.

Wide spread arsenic poisoning

When the first water bubbled from wells sunk deep into the soils of West Bengal in India a generation ago, locals called it the devils water. Historically the villagers have used surface water but with new tube wells tapping water from more than 150 meters below ground they can now grow three or four crops. But those talking about devils water soon changed their minds as the water irrigated rice crops all year round and brought new prosperity to their villages.

However the water contained high levels of arsenic and for hundreds of thousand of villagers the improved harvest has proved bitter. More than 400 villages have been affected across West Bengal and the world's largest arsenic poisoning so far has left more than 600,000 people disfigured and facing an early death.

Studies beneath the villages have revealed a series of layers of sedimentary rocks containing arsenic, mostly in seams of iron pyrite which contaminated many wells. Overpumping has also lowered the water table in many rocks. As the water table has fallen the arsenic bearing sulfide rocks dried out (one of a couple of existing theories), oxygen penetrated the rocks oxidizing the sulfur minerals. This has freed the arsenic to be dissolved in the groundwater and washed into the wells. Today more than 700 wells supply water that contains more than 10 mg of arsenic/l, the maximum limit set by WHO. Average arsenic levels are between 20 and 70 times the WHO maximum with individual wells up to 200 times the limit. Arsenic in groundwater above the WHO maximum permissible limit has been found in 6 districts in West Bengal with a population of 30 million.

International incidents of arsenic contamination in groundwater and the consequent state of health of people have also been widely reported from other places (Fig. 4). The arsenic contamination incident in the well-water of Taiwan (1961-1985) caused an illness called black foot disease. The population of the endemic area was about 100,000. Similar problems were reported from Antofagasta in Chile where almost 100,000 people out of a total population of the city of 130,000 were drinking water with elevated arsenic content for 12 years between 1959 and 1979. Chronic arsenic poisoning is also reported in some parts of the Lagunera Region, Mexico. The arsenic concentration in groundwater was 0.41 mg/l.

Table 2 – Diseases at state of deficiency respectively toxicity caused by the same element

Element	Deficiency	Toxicity
Iron	Anaemia	Haemochromatosis
Copper	Anaemia "Sway back"	Chronic copper poisoning Wilson-, Bedlington-disease
Zinc	Dwarf growth Retarded development of gonads Akrodermatitis entero-pathica	Metallic fever Diarrhoea
Cobalt	Anaemia "White liver disease"	Heart failure Polycythaemia
Magnesium	Dysfunction of gonads Convulsions Malformations of the skeleton Urolithiasis	Ataxia
Chromium	Disturbances in the glucose metabolism	Kidney damage (Nephritis)
Selenium	Liver nechrosis Muscular dystrophy ("White muscle disease")	"Alkali disease" "Blind staggers"

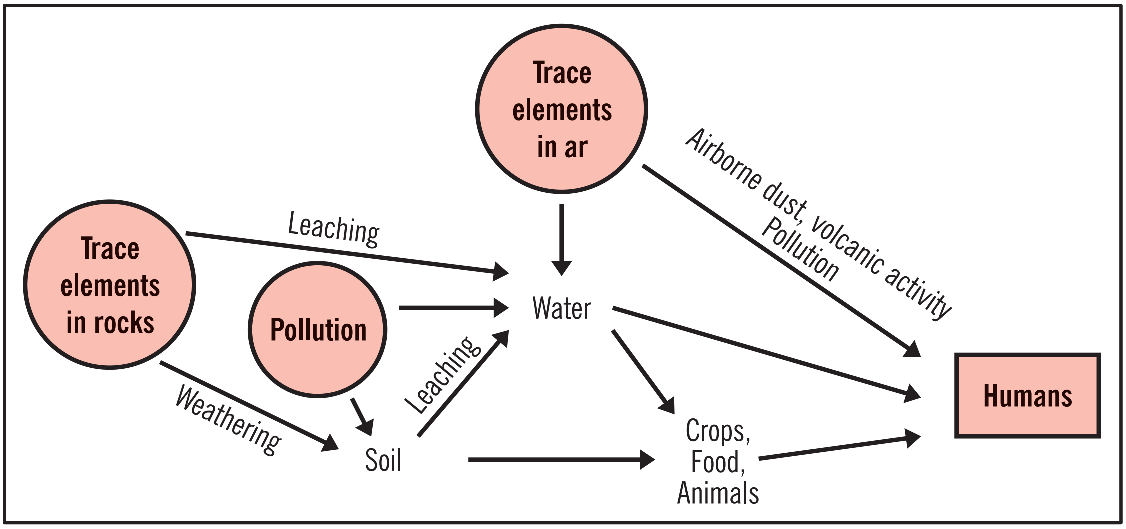

Figure 3 – Pathways through which trace elements enter the body

Similar incidents were also reported in Argentina in 1955. Many other minor incidents are also reported from many parts of the world.

Present activities

Because of the importance of geological factors on health and the general lack of appreciation in understanding the importance of geology in such relationships, Cogeoenvironment (Commission on Geological Sciences for Environmental Planning) decided in 1996 to establish an International Working Group on Medical Geology with the primary aim of increasing awareness of this issue among scientists, medical specialists, and the general public. The working group had more than 300 members from more than 50 countries throughout the world in 2002.

In 2000 a new "IGCP" project was also established by Unesco (a 5 year project); "IGCP#454 Medical Geology". This project was integrated in the Working Group on Medical Geology. IGCP is a co-operative enterprise of Unesco (United Nations Educational, Scientific and Cultural Organization) and IUGS (International Union of Geological Sciences) to facilitate geological co-operation across international borders, as geological processes and structures normally cut across such boundaries. The program's major aim was to bring together scientists from East and West and to encourage the involvement of developing countries. The International Geological Correlation Programme is carried out through individual projects. Their number is not defined but is controlled by the available financial resources and by scientific peer review of project

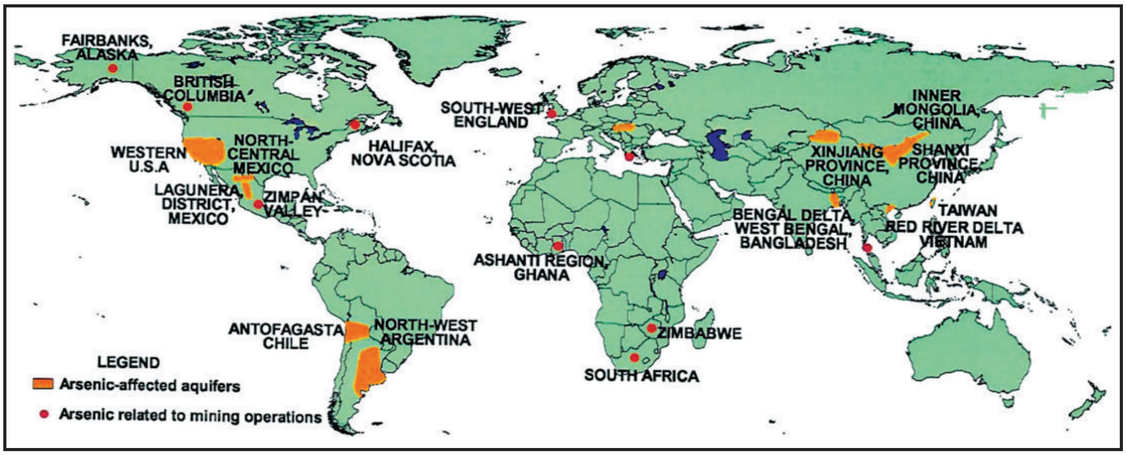

Figure 4 – Examples of arsenic contamination

proposals and of annual reports of progress. The established lifetime of an IGCP project is usually five years.

The primary aim of the new IGCP project is to bring together, at the global scale, scientists working in this field in developing countries with their colleagues in other parts of the world, stressing the importance of geoscientific factors that affect the health of humans and animals. The project has the potential to build in capacity, involving transfer of training as well as mutual exchange of information and experience. The developing world will provide considerable case study and research potential. For their part, the developed countries will offer their advanced techniques and research skills with appropriate transfer of medical knowledge and methodology. This initiative provides, for the first time, the opportunity for leading scientists from developing countries to come together in a truly international and interdisciplinary way (involving geoscientists, physicians and veterinarians) to identify and tackle real problems of geoenvironment and health.

A series of short courses on metals, health and the environment are also carried out all around the world. The Scope and Purpose of the courses are as follows: Metal ions occur naturally in rocks, soils, gases, and waters in both harmless and harmful forms and concentrations. Natural concentrations can be extraordinarily high and have caused serious health problems. Metals are important to environmental health and to the study of human diseases (pathology) because of their potential toxic effects on one or more organs. Exposure to toxic metal ions may occur via three principle routes: percutaneous absorption, ingestion, or inhalation. Dermal toxicity results from local tissue responses through direct contact of the metal with skin, or alternatively, may represent a manifestation of systemic toxicity following ingestion or inhalation. Allergic contact dermatitis induced by nickel is an example of a local tissue response. The adverse cutaneous reactions resulting from chronic ingestion or inhalation of arsenical compounds exemplify systemic toxicity. A variety of toxic pathology responses in human tissues and organs (i.e., skin, liver, heart, kidney) associated with both acute and chronic exposure to metals are described. The aim of the courses is to provide examples where both deficiencies of trace elements as well as toxic exposures of metals may be involved in physiological changes and the development of human diseases. We discuss the impacts of metal ions and trace elements on human health as illustrated with examples of arsenic poisoning from contaminated water in the Bengal Delta (India and Bangladesh) and Taiwan, as well from coal combustion in southwest China. Studies associated with lung cancer risk in an occupational cohort of chromate production workers are described. An overview of clinical aspects of toxic metal exposures including discussions of essentiality and clinical manifestations are presented. The courses are intended for geologists, ecologists, chemists, biologists, occupational and environmental scientists, medical professionals, toxicologists, epidemiologists, pathologists and any other health, environmental and geosciences professional with interest on the effect of toxic metal ion species on environmental and human health. An important aim of the courses are to provide the opportunity for forming contacts and networks between professionals working in different areas of the field.

Short Course Leaders are Dr. José A. Centeno, Chief, Biophysical Toxicology Division, United States Armed Forces Institute of Pathology, Washington DC and Dr. Robert B. Finkelman, Coal Quality Coordinator, Research Scientist, United States Geological Survey, Reston, VA, USA and Dr. Olle Selinus, Geological Survey of Sweden.

It has also been decided to publish a new book "Medical Geology" to be published in 2003 with about 60 distinguished authors (physicians and geoscientists) involved from all over the world. The audience of the book will be junior to senior undergraduates and educated decision-makers. The main objective is to emphasize the importance of geology in health and disease in humans and animals. The book will contain 4 sections. *Section 1* is meant to be a general background for geoscientists, physicians and vets and are very important for all readers in order to be able to fully understand the rest of the book. *Section 2* will cover Medical Geology, the effects of our natural environment (geology) on health. There is also a chapter on anthropogenic sources in this section because it sometimes is impossible to discriminate between natural and anthropogenic sources. *Section 3* will cover epidemiology and *Section 4* covers the techniques and tools our different sciences use and which could be used by each other. There will also be an appendix with tables on guideline values, reference values etc.

Several examples of Medical Geology will be presented such as the Keshan disease, Kashin Beck disease in China (selenium deficiency), arsenic poisoning in Bangladesh and Bengal, diabetes, cardio-vascular diseases, radon, geophagia (the deliberate eating of soil), the mysterious moose disease in Sweden etc. Also examples of iodine, fluorine and other elements will be mentioned.

Future

Medical Geology is therefore an emerging discipline and a science which will grow rapidly. Several geological surveys are integrating Medical Geology in their work and Medical Geology is now taught in some university courses for medical students. In the future it will be important to improve communication amongst the various disciplines concerned with diseases caused by geological factors which influence the well being of humans and animals. It will also be important to develop information material for the use of schools, public and private organizations interested in Medical Geology problems to show the impact of geologic factors on the well being of humans and animals, as well as arranging joint technical meetings to address issues of mutual concern amongst geoscientists and other disciplines concerned with Medical Geology. Geological surveys, universities and geological and medical societies should take a more active role in providing useful information on geologic conditions in medical geology and encourage the development of local working groups of multi-disciplinary Medical Geology experts. It would also be useful to encourage research in the area of producing more effective methodologies for the study of geological factors in environmental medicine and formulate recommendations for mitigation of effects of natural and man-induced hazardous geochemical conditions. Medical Geology is thus an interdisciplinary science which will be heard of increasingly in the future.

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