Medical Geology – a new future for Geoscience

by Olle Selinus[1], Robert B. Finkelman[2], Jose A. Centeno[3] and Kaj Lax [1]

Medical geology is the science dealing with the influence of geology on the distribution of health problems in humans and animals. This is a complicated subject and interdisciplinary contributions from essentially different scientific fields are required when these problems are to be solved. This paper discusses the background of medical geology with examples from all over the world. All living organisms, are composed of major, minor and trace elements, given by nature and supplied by geology. Medical Geology is a rapidly growing discipline that has the potential of helping medical and public health communities all over the world pursue a wide range of environmental and naturally induced health issues. The paper also describes ongoing and future activities in medical geology.

La géologie médicale est la science qui traite de l'influence de la géologie sur la santé de l'homme et des animaux. Il s'agit d'un sujet complexe et il est indispensable pour résoudre les problèmes posés de faire appel à des sources scientifiques interdisciplinaires, dans des secteurs très différents. L'article expose les fondements de la géologie médicale à partir d'exemples tirés du monde entier. Tous les organismes vivants sont composés d'éléments majeurs, secondaires et sous forme de traces, créés par la nature et livrés par la géologie. La géologie médicale est une discipline en expansion rapide qui a la possibilité d'aider le personnel médical et les organismes de santé, dans le monde entier, à faire face à un grand nombre de problèmes de santé liés à des causes environnementales et naturelles. Cet article décrit aussi les travaux actuels et futurs de la géologie médicale.

La geología médica es la ciencia que trata de la influencia de la geología en la distribución de la salud en humanos y animales. Es un tema complicado y es precisa la contribución interdisciplinar de campos científicos esencialmente diferentes cuando se desea resolver estos problemas. Este trabajo analiza el trasfondo de la geología médica con ejemplos de todo el mundo. Todos los organismos se componen de elementos mayores, menores y traza, aportados por la Naturaleza y proporcionados por la geología. La Geología Médica es una disciplina que crece rápidamente, que tiene el potencial de ayudar a las comunidades médica y de protección de la salud de todo el mundo en un amplio rango de temas ambientales y de salud inducidos naturalmente. El trabajo también describe las actividades en marcha y las futuras de la geología médica.

Medical Geology is a rapidly growing field concerned with the relationship between natural geological factors and human and animal health, as well as with improving our understanding of the influence of environmental factors on the geographical distribution of health problems. Medical Geology brings together geoscientists and medical/public health researchers to address health problems caused, or exacerbated by geological materials (rocks, minerals, atmospheric dust and water) and processes (including volcanic eruptions and earthquakes). Among the environmental health problems that geoscentists are working on in collaboration with the medical and public health community 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. (Fig. 1). Medical geology also deals with the many health benefits of geologic materials and processes.

[1]Geological Survey of Sweden, Uppsala SE-751 28, Sweden
[2]U. S. Geological Survey, MS 956, Reston, VA, 20192 USA
[3]U. S. Armed Forces Institute of Pathology, Washington, DC 20306-6000 USA

Deficiency, toxixity and bioavailability

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 irregular distribution of essential elements in the natural environment can lead to serious health problems particularly for populations who are heavily dependent on the local environment for their food supply. Approximately 25 naturally occurring elements are known to be essential to plant and animal life in trace amounts; these include calcium, magnesium, iron, cobalt, copper, zinc, phosphorus, nitrogen, selenium, iodine and molybdenum. On the other hand, an over-abundance of these elements can cause toxicity problems. Some elements such as arsenic, cadmium, lead, mercury and aluminium have no or limited biological function and are generally toxic to humans in even small exposures.

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 programmes are widely practised in agriculture and in animal husbandry. Trace element deficiencies generally lead to poor crop and animal growth, poor yields, and to reproductive disorders in animals. These

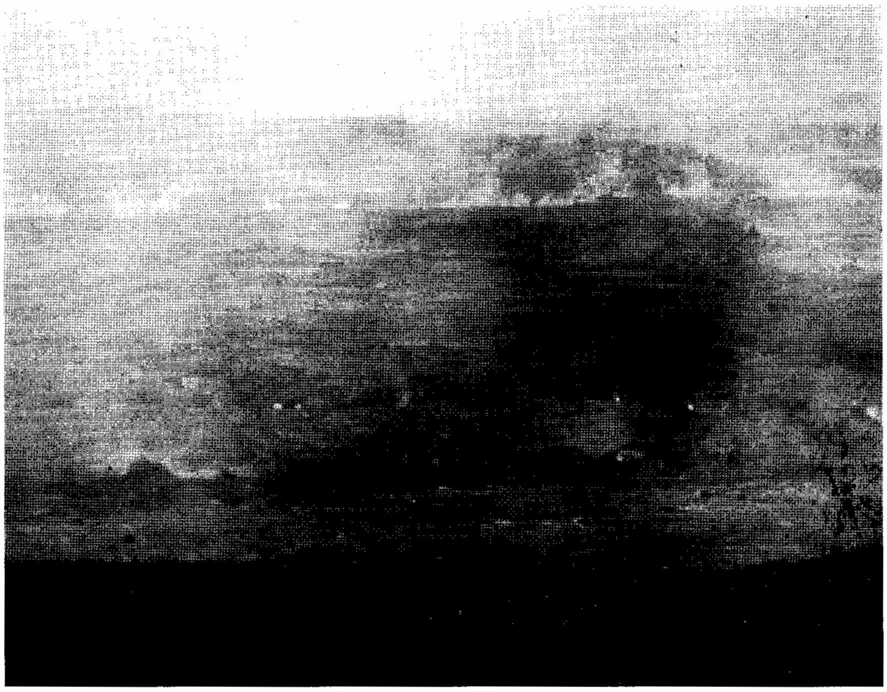

Figure 1. Krafla, Iceland. (Photo: O. Selinus)

problems often have greatest impact on poor populations who can least afford mineral interventions.

In addition to understanding both natural and anthropogenic sources of harmful substances in the environment, it is also important to consider exposure and bioavailability. Bioavailability directly influences exposure and, therefore, the effect on and risk to health. Large quantities of potentially harmful substances may be present in the environment, but if they are in a non-bioavailable form, the risk to health may be minimal. Bioavailability depends not only on the physical and chemical forms in which the element is present, but also on local factors in the environment, for example pH. The bioavailability and mobility of metals such as zinc, lead and cadmium is greatest under acidic conditions, while increased pH reduces bioavailability. Also soil type, for instance clay and sand content, and its physical properties, affects the migration of metals through soils. The organisms present in soils also affect metal solubility, transport, bioavailability, and bioaccessibility

Trace element exposure: deficiency and toxicity

The study of trace elements is one of the most important topics in medical geology. The following examples are just a few that have relevance to Europe.

The connection between geological 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. 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, but also in Europe 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 (Fuge, 2005).

Another important element is fluorine. The geochemistry of fluorine in ground water and the dental health of communities, particularly those depending on groundwater for their drinking water supplies, is one of the best known relationships between geochemistry and health. Many water supply schemes contain excess fluorine and as such are harmful to dental health. For most trace elements required by humans and other animals, food is the principle source. In the case of fluorine, however, much of the input into the human body is from drinking water and the geochemistry of fluoride in groundwater is therefore of particular significance in the etiology of dental diseases. After, for example, the eruptions of the volcano Hekla on Iceland in 1693, 1766 and 1845, detailed descriptions of fluorosis were presented. Acute poisoning was described. Since World War II Hekla has had eruptions in 1947, 1970 and 1980 and a number of analyses of fluorine have been performed. The volcano delivered huge amounts of fluorine and concentrations as high as 4300 mg/kg in grass have been found.

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) (Fordyce, 2005). Several areas in the world are selenium deficient and among them in Europe are Sweden and Finland.

Arsenic and arsenic-containing compounds are human carcinogens. Exposure to arsenic may occur through several anthropogenic processes, including mining residues, pesticides, pharmaceuticals, glass and microelectronics, but the most prevalent sources of exposure today are 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. The source of arsenic is geological, the element being present in many rock forming minerals. There is growing concern about the toxicity of arsenic and the health effects caused by exposure to elevated concentrations of it in the geochemical environment. The danger to human health due to arsenic poisoning has been recognized by WHO and the provisional guideline value for arsenic in drinking water has been lowered from 50 μg/l to 10 μg/l. Among the countries that have well documented case studies of arsenic poisoning are Bangladesh, India (West Bengal), Taiwan, China, Mexico, Chile and Argentina, but also several countries in Europe such as Hungary, Sweden, UK etc. The common symptoms of chronic arsenic poisoning are depigmentation, keratosis and hyperkeratosis.(Smedley, Kinniburgh, 2005).

Medical geology in Sweden

Human beings are the last link in the food chain, but also earlier links in the chain are evidently influenced by geochemistry. During the second half of the 1980s, a previously unknown disease was reported in the moose population in south-west Sweden. The region is strongly affected by acid rain and to counteract the negative effects of acidification of lakes and wetlands, liming was intensified during the second half of the 1980s, which corresponded with the outbreak of the disease. Chemical investigations of moose organs collected in connection with regular moose hunts in the affected region, have shown that the hepatic copper concentration decreased by 50 %, and cadmium by about 30% during a period of 10 years. During the same time molybdenum concentration increased significantly by between 22 and 40%. The cause of the moose disease appears to be severe copper deficiency and molybdenosis. In those areas where we have high natural contents of molybdenum bedrock and soils, liming increases the mobility of molybdenum and decreases the mobility of copper, the copper/molybdenum ratio changes and the moose are strongly affected by this change in the environment. This side effect of liming and its harmful consequences for domestic and wild ruminants appears to have been overlooked (Fig. 2).

Diabetes presents one other example of the use of geochemistry in medical geology. Childhood diabetes is almost exclusively of the insulin-dependent type (type1). A case control study in Sweden was designed comparing zinc contained in biogeochemical samples from different areas. The results showed that a high water concentration of zinc was associated with a significant decrease in risk. This provides evidence that a low groundwater content of zinc, which may reflect long-term exposure through drinking water, may be associated with later development of childhood onset diabetes.

Cardiovascular diseases have also been studied using biogeochemistry. In has been shown that water hardness (calcium + manganese and other minor constituents) and the sulphate and bicarbonate concentrations of drinking water are inversely related to ischaemic heart disease as well as stroke mortality. The variation in the drinking water composition reflects the geological variation of the elements.

Radon – common in many places in Europe

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

Figure 2. Moose

is controlled largely by the types of minerals in which uranium and radium occur. Once radon gas is released from minerals, its migration to the surface is controlled by the permeability of the bedrock and soil, the nature of the carrier fluids, (including carbon dioxide gas and groundwater), and meteorological factors such as barometric pressure and rainfall. Geological radon potential maps derived from a range of data including radon measurements in soil and dwellings; soil and rock permeability; uranium concentrations in rocks and soils; and gamma spectrometric data show the relative health hazards from radon. Whereas a geological radon potential map can indicate the relative radon hazard, it cannot predict the radon risk for an individual building. This can only be established by having the building tested.

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 in the next few years (Orem *et.al.*, 1999). There is growing evidence that toxic organic compounds present in the drinking water of the endemic areas leached by groundwater from low rank Pliocene lignite deposits and were 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 than 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 connection between leachable organics from the coal and organics in the water samples. The population of villages in the endemic areas uses almost exclusively well/spring water 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 favour relatively slow development of the disease over a time interval of 10 to 30 years or more. This disease is now also suspected to occur in the USA, Portugal and Turkey. Collaborative research between geoscientists and medical scientists is now going on in these countries.

Global dust

Dust is a global phenomenon. Dust storms from Africa regularly reach the European Alps, and the Western hemisphere and Asian dust outbreaks can reach California in less than a week, some ultimately crossing the Atlantic and reaching Europe. The ways in which mineral dust impacts upon life and health are wide-ranging. These include changes in the planet's radiative balance, transport of disease bacteria to densely populated regions, dumping of wind-blown sediment on pristine coral reefs, general reduction of air quality, provision of essential nutrients to tropical rainforests and transport of toxic sub-

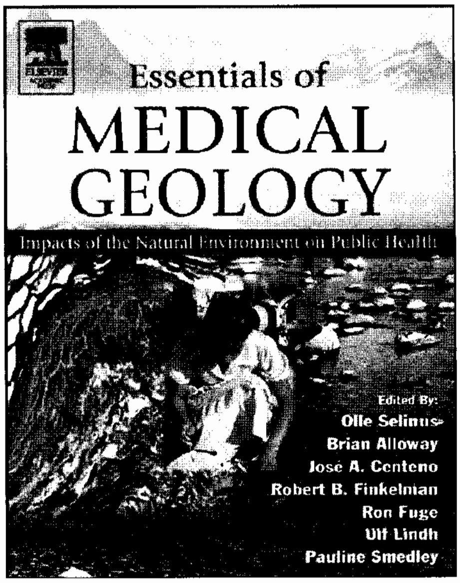

Figure 3. "Essentials of Medical Geology"

stances. Mobilization of dust is both a natural and a humanly triggered process. Changing climatic conditions play a key role as natural changes occur in available moisture and wind speeds. Although vegetation exerts a critical control on dust mobility, vegetation itself is influenced by climate, human activity and other factors. A better understanding of dust, including the processes that control its sources and transport as well as its impacts, is needed if its negative consequences are to be mitigated (Derbyshire, 2005).

International Medical Geology Association (IMGA)

The development of Medical Geology was given a major boost in 1998 following the creation of an International Working Group on Medical Geology within the IUGS Commission on Geological Sciences for Environmental Planning (COGEOENVIRONMENT). The primary aim of the Working Group was to increase awareness of this issue among scientists, medical specialists, and the general public. That Working Group was so successful that in 2000 the IUGS took over the project as a Special Initiative which was subsequently accepted as "IGCP project 454 MEDICAL GEOLOGY". IGCP project 454 was initially designed with a life span of 5 years and in that time Medical Geology expanded rapidly to become a global matter and the acceptance and response has been outstanding. Many courses (more than 30) have been presented around the world since 2001 (Fig. 4); many papers have been published; thousands of people have become deeply involved; many students are now inquiring about pursuing their professional degree in medical geology. The first ever comprehensive book on medical geology *"Essentials of Medical Geology"* was published in 2005 (Selinus et al., 2005). This work of 812 pages, has 31 chapters, written by equal numbers of geoscientists and medical specialists (Fig 3). The book was awarded a prestigious "Highly Commended" title in the Public Health category by the British Medical Association which recognized this as one of the best of all published Public Health books in 2005. It has also received one of the two 2005 Geology/Geography Awards for Excellence from the Professional and Scholarly Publishing (PSP) division of the Association of American Publishers. The PSP awards recognize both editorial standards as well as design and production standards (see book review page 42).

In order to continue the development of this emerging discipline of Medical Geology the managers of the IGCP project, with approval from a special meeting at the International Geological Congress in Florence in 2004, formed, in January 2006, a new association, the International Medical Geology Association (IMGA). The IMGA is planning a significant involvement in the UN proclaimed 2008 (2007-2009) International Year of Planet Earth (Earth Science for Society) the first ever UN Year for the Earth Sciences.

For more information see:
www.medicalgeology.org

References

Derbyshire, E. 2005. Natural aerosolic mineral dusts and human health. In, Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., and Smedley, P. (Editors), *Essentials of Medical Geology*. Elsevier, Amsterdam, 812 pp.

Fordyce, F. 2005. Selenium deficiency and toxicity in the environment. In, Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., and Smedley, P. (Editors). *Essentials of Medical Geology*. Elsevier, Amsterdam, 812 pp.

Fuge, R. 2005. Soils and iodine deficiency. In, Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U. and Smedley, P. (Editors). *Essentials of Medical Geology*. Elsevier, Amsterdam, 812 pp.

Orem, W. H., Feder, G. L., and Finkelman, R. B. 1999. A possible link between Balkan endemic nephropathy and the leaching of toxic organic compounds from Pliocene lignite by groundwater: preliminary investigation. *Int. Jour. of Coal Geol.*, Vol. 40, Nos. 2-3, pp 237-252..

Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., and Smedley, P. (Editors). 2005. *Essentials of Medical Geology*. Elsevier, Amsterdam, 812 pp.

Smedley, P., Kinniburgh, D.G. 2005. Arsenic in Groundwater and the Environment. In, Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., and Smedley, P. (Editors), *Essentials of Medical Geology*. Elsevier, Amsterdam, 812 pp.

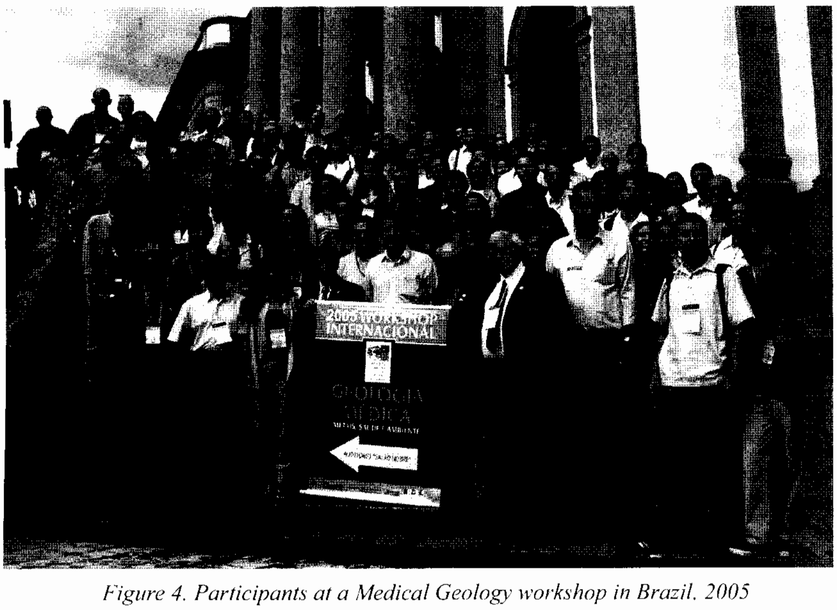

Figure 4. Participants at a Medical Geology workshop in Brazil. 2005