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Geochemistry and Health, Why Geoscience Information is Essential

Fiona Fordyce, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK
f.fordyce@bgs.ac.uk

Geochemistry and Health

Geochemistry in its strictest sense is the study of rock chemistry and at first glance it may seem there is little connection between the composition of rocks and human health. However, the various rock types that make up the surface of the planet comprise different mineral assemblages, which contain the 92 naturally occurring chemical elements found on Earth. Many of these elements are essential to plant, animal and human health in small doses, we all know that we need enough calcium in our diets to keep our teeth and bones healthy, for example. We intake most of these elements through the food we eat, the water we drink and the air we breathe. Through physical and chemical weathering processes, rocks break down to form the soils on which we grow our crops and raise the animals that make up our food supply. The water that we drink travels through rocks and soils as part of the hydrological cycle and much of the dust and some of the gases contained in our 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 (Figure 1).

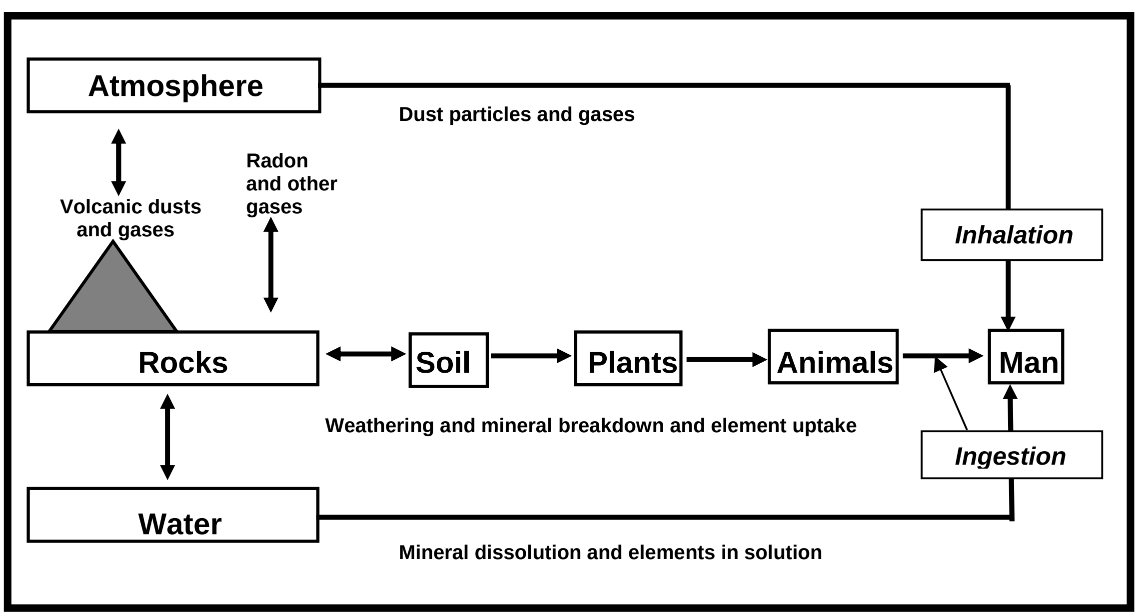

Figure 1. Simplified schematic diagram of the cycling of chemical elements from the geosphere into man.

These links are particularly important for developing country subsistence farmers who depend on their immediate environment for food and have little access to goods outside their area. The inability of their environment to provide the correct mineral balance can lead to serious health problems. 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).

Essential and Toxic Elements

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 some of these elements can cause toxicity problems. Some elements have no/limited biological function and are generally toxic to humans. These include As, Cd, Pb, Hg and Al (Table 1).

Table 1. Some chronic diseases and disorders that may be linked to element deficiencies and toxicities.

Deficiency		Toxicity	
I	Goitre, cretinism	Cd	Renal and heart diseases
Fe	Anaemia	Pb	Neurological disorders
Ca, Mg, Na	Cardiovascular disease	Hg	Neurological disorders
Cr	Glucose regulation	As	Cancer, skin disease
Co	Pernicious anaemia	Rn	Lung cancer
Zn	Enzyme and skin disorders	Se	Hair loss, nervous disorders
Se	Heart disease, cancer	F	Dental caries, bone disorders

Geochemistry and Agriculture

Most of these elements are known as trace elements because their natural abundances on Earth are generally very low (µg/g 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. Trace element deficiencies generally lead to poor crop and animal growth, poor yields, and to reproductive disorders in animals. These problems often have greatest impact on poor populations who can least afford mineral interventions for their animals.

Often, the uptake of elements into plants and animals is controlled by a number of geochemical factors such as soil pH, organic matter content and Eh conditions. These factors greatly influence the mobility of elements in the environment and determine how readily available elements are for plant and animal uptake (bioavailability). An understanding of the geochemical processes involved in cycling essential elements through the environment is therefore essential to develop effective remediation strategies.

Iodine Deficiency Disorders in Man

Trace element deficiencies also affect man. In the case of iodine, the main environmental source is seawater, however, its abundance in most terrestrial environments is very low, normally a few µg/g in most soils. Low dietary intakes of iodine have been linked with a set of conditions in man known as iodine deficiency disorders (IDD). Iodine is involved in the processing of growth hormones in the thyroid gland and in most cases iodine deficiency manifests itself as goitre. Goitre is the enlargement of the thyroid gland as it attempts to compensate for insufficient iodine (Figure 2). Iodine deficiency in pregnant mothers can also lead to cretinism and impaired brain function in children. These are serious and debilitating consequences, particularly for poor populations, as the capability of children is severely restricted and they become a burden on the family. The World Health Organisation estimates that over 1.6 billion people are at risk from iodine deficiency and that it is the single largest cause of mental retardation in the world today.

The link between environmental iodine and IDD has been known for the last 80 years. During this time, many aid agencies and governments have attempted to solve the problem by increasing dietary intake of iodine via the introduction of iodised salt and iodised oil programmes. Despite these interventions, IDD remain a major problem globally. It is likely that IDD are multi-causal diseases involving factors such as trace element deficiencies, goitre-inducing substances in foodstuffs (known as goitrogens) and genetics. However, geochemists have an important role to play in determining the environmental cycling of iodine and its uptake into the food chain if levels of dietary iodine are to be enhanced successfully.

Selenium Deficiency and Toxicity

The British Geological Survey (BGS) recently completed a study into Se deficiencies and toxicities in China funded by the UK Department for International Development (DFID). Selenium is an interesting element because the concentration range between deficiency (< 11 µg/day) and toxicity (> 900 µg/day) is very narrow. In the human body, Se forms part of the essential enzyme glutathione-peroxidase (GSH-Px) and acts as an anti-oxidant preventing tissue damage. Selenium deficiency has been linked to a heart disease called Keshan Disease, named after the Chinese district of Keshan where it was first discovered. The disease results in damage and enlargement of the heart muscles which eventually leads to death. Keshan Disease occurs in a belt stretching from the north-west to the south-east of China and is coincident with remote populations living in areas of low environmental Se in soils and crops. Selenium toxicity is far less widespread, occurring in discrete areas, and results in hair and nail loss and nervous disorders in the local population.

In Enshi District, Hubei Province, these diseases occur with-in 20 km of each other, their incidence being controlled by geology. The north-west of Enshi District is underlain by sandstones, which contain low concentrations of trace elements including Se. Keshan Disease is present in this area. Selenium toxicity, on the other hand, is associated with high environmental Se derived from coal-bearing strata in the centre and east of the District.

In the Keshan Disease areas, studies revealed that the Se concentrations in staple food crops (rice and maize), drinking water and the human populations (measured in hair samples) were very low. Although the amount of Se in the soil was also reasonably low, the problem of Se deficiency was exacerbated, due to high organic matter contents and low pH of the soil. Selenium is more mobile at higher pH hence the low pH was restricting Se bioavailability. Selenium in the soil was also adsorbed onto organic matter making it less available for plant uptake. This has important implications for the development of remediation strategies because adding Se-rich fertiliser to the soil, for example, may not increase the Se contents of the plants. The Se may remain trapped in the soil by the organic matter. A more appropriate approach may be to condition the soil with lime to increase the pH making Se more mobile.

In the Se toxicity areas, investigations showed that concentrations of Se in soils and foodstuffs could vary markedly from low to toxic within the same village, these variations being dependent on the outcrop of the coal-bearing strata. Villagers were therefore advised to avoid cultivating fields underlain by the coal and were counselled against using coal-derived products, such as ash, to condition the soil.

Toxicity and Mineralised Areas

In addition to being essential to health, many of these trace elements are also of economic interest (Cu, Pb, Zn, Hg, Cr etc.) or they occur in association with economic minerals (As and Au, for example). The greater abundance of these elements in mineralised zones and the enhanced dispersion of these elements into the environment via processes such as mining, can lead to toxicity problems. In these cases, an understanding of the geochemistry is also important to determine migration pathways and exposure routes to plant, animal and human populations. Furthermore, toxicity is often dependent on the mineral and chemical form of the element, for example, As^{3+} is much more toxic than As^{5+}.

Mercury toxicity problems associated with mining can result from the use of Hg to process gold whereby miners are exposed to Hg vapours during the burning-off of Hg-Au amalgams. More widespread environmental problems can arise due to increased sediment loadings in rivers as a result of the mining activity itself. Organic-(methylated)-mercury is an excellent bioaccumulator and concentrates in aquatic organisms such as fish. Many fish-eating communities in and around mining areas can therefore be affected by enhanced environmental concentrations of mercury.

Environmental Toxicity

Even outside mineralised areas, natural abundances of potentially toxic elements can cause problems such as the current As in groundwater situation in Bangladesh. In the last 20 – 30 years, aid agencies etc. have constructed many deeper wells and boreholes to avoid surface waters contaminated with disease and to meet the demands of a huge explosion in population and agriculture. Unfortunately, the geochemical characteristics of water from these deeper aquifers were not considered and although the aquifer sediments are not mineralised, the concentrations of As present are enough to cause serious health problems. It is estimated that 200 000 people have developed

As poisoning including skin and internal organ cancers and that 20 – 30 million people are drinking water which exceeds the Bangladesh toxicity limit (0.05 mg/l).

The presence of high F in drinking water is also a problem over many areas of the world. Too much F in the diet causes disruption of bone and teeth forming functions and can lead to dental caries and skeletal deformities. It is estimated that an excess of fluoride affects 25 million people throughout India alone.

The Importance of Geoscience

Clearly there is a link between the cycling of chemical elements through the natural environment and adverse effects on the human body. These problems literally affect billions of people world-wide, many of which are the poorest in society. The cycles and effects are very complex involving interactions between the geosphere, atmosphere, hydrosphere and biosphere and a multi-disciplinary approach is necessary to combat these problems.

Geoscientists have been investigating the links between geochemistry and health for the past 50 years but this subject has become of increasing importance in the last 15 – 20 years due to the impact of man on the environment at the global scale. In recognition of the increasing importance of this subject area, the International Union of Geological Sciences (IUGS) recently established a Working Group on Medical Geology. The International Council of Sciences (ICSU) has also established a Research Agenda on Health and Environment. The IUGS will shortly initiate a Working Group on Mineralogy, Geochemistry and Health.

These Working Groups aim to increase collaboration between geoscientists and medical/biological scientists and to demonstrate that geoscientsts have an important role to play in these health and development issues.

Further Information:

The British Geological Survey is interested in geochemistry and health issues world-wide. For further details or information contact Fiona Fordyce, British Geological Survey, Keyworth, Nottingham, NG12 5GG, UK. E-mail: f.fordyce@bgs.ac.uk

Further information on Department for International Development projects can be found at http://www.bgs.ac.uk.dfid-kar-gescience/summaries.html

Further information on the IUGS Working Group on Medical Geology is available from Dr Olle Selinus, Geological Survey of Sweden, PO Box 670, SE 75128 Uppsala, Sweden. E-mail: olle.selinus@sgu.se
The project web-site is at http://home.swipnet.se/medicalgeology

Further information on the ICSU Research Agenda on Health and the Environment is available from Prof Mark Rosenberg, Dept of Geography, Queens University, Kingston, Ontario, K7L 3N6, Canada. E-mail: rosenber@post.queensu.ca
The project web-site is at http://post.queensu.ca/~jlj/healthandenvir

Further information on the IUGS Working Group on Mineralogy, Geochemistry and Health is available from Prof Catherine Skinner, Dept of Geology and Geophysics, Yale University, Box 208109, New Haven, CT 06520-8109, USA. E-mail: catherine.skinner@yale.edu

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