

ESSAY

GLOBAL VOICES OF SCIENCE

Of Stones and Health: Medical Geology in Sri Lanka

Chandra Dissanayake



To most people, geology is a subject concerning rocks and minerals and their distributions on Earth. As an Earth science, of course, geology also deals with physical processes of the Earth, such as mountain building, coastal and river dynamics, and desert formation. Few people know that geoscientists have expanded their discipline by linking human and animal health with geology. The fundamental basis for this expansion, which has spun into a specialty known as medical geology, is the unique interdependence of the different living and nonliving components that make up the Earth. The basic building blocks of the Earth—the rocks and minerals—must, therefore, have a bearing on the health of the human and animal populations that live on these earthy materials.

Once a little-known specialty among a few geologists around the world, medical geology is now recognized as a field unto itself. Established by the International Union of Geological Sciences in early 1990, the Commission on Geological Sciences for Environmental Planning (COGEOENVIRONMENT) has defined medical geology as “the science dealing with the influence of ordinary environmental factors on the geographical distribution of health problems in man and

animals.” It now has developed into a truly fascinating new science, with potentially enormous consequences for the well-being of people around the world.

We Are What We Eat and Drink

On our planet, the chemical elements flow through the different planetary compartments, including the atmosphere, hydrosphere, lithosphere, and biosphere. Humans and animals are part of these cycles. The chemical elements pass into and out of them, too, in a complex biogeochemical cycle. Obviously, then, the chemistry of any local geological environment must have a direct influence on the chemical make-up of those living there. This is most readily seen in places where humans live in particularly intimate contact with the local physical environment, as is the case with rural people living in tropical countries. Those living on lands with heavily impoverished soils, such as in Maputaland, south Africa, have such a low intake of essential elements that a very large percentage of the population suffers from a variety of diseases caused by severe mineral imbalances. Likewise, in other areas, there is an excess intake of elements due mainly to the abundance of certain elements in the environment. This leads to high incidences of mineral toxic-

ity, such as the widespread and tragic arsenic poisoning in India and Bangladesh.

Even though many other factors—among them life-style, sex, age, migrations, and food habits—affect health, imbalances in the supply of inorganic elements exert marked influences on both human and animal health. Anomalies in the local abundances of trace elements, for example, have a large impact on food chains. As it was more than 500 years ago, it remains relevant to bear in mind the basic law of toxicity as defined by Paracelsus (1493–1541), the father of pharmacology: “All substances are poisons; there is none which is not a poison. The right dosage differentiates a poison and a remedy.” Even water, when consumed too quickly and in inordinate amounts, can be lethal.

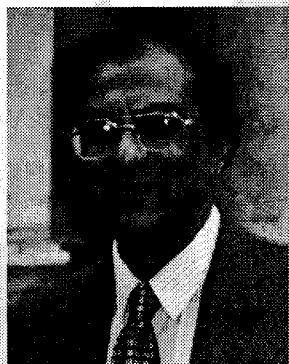
One of the primary objectives of medical geologists, therefore, is to determine the optimal exposures for people to the essential elements in order to maintain or improve health. Diseases such as hyperkalemia (due to excess potassium), hypercalcemia (due to excess calcium), and hyperphosphatemia (due to excess phosphorus) exist in various parts of the world even though potassium, calcium, and phosphorus are essential dietary elements.

I have studied a number of specific cases that illustrate how optimal amounts of trace elements are needed to maintain good health and how an imbalance in these elements can lead to disease.

This yearlong essay series celebrates 125 years of *Science* by inviting researchers from around the world to provide a regional view of the scientific enterprise. Series editor, Ivan Arnato

Chandrasekara Dissanayake Sri Lanka

Chandra Dissanayake, a senior professor of geology at the University of Peradeniya, Sri Lanka, has pioneered geochemical research in Sri Lanka. He is the only Sri Lankan to have obtained both D.Phil. and D.Sc. degrees from Oxford University, UK. From the very beginning of his research career, he sought avenues off the beaten track of routine geology by exploring the boundaries between geology and other scientific areas. For nearly 30 years he has carried out research in the little-known field of medical geology and has published many research papers on the topic. He is a recipient of the National Award for Science in Sri Lanka and the Gold medal of the Institute of Chemistry, Sri Lanka, in recognition of his groundbreaking research on applied geochemistry. He is a fellow of the Academy of Sciences for the Developing World (TWAS), headquartered in Trieste, Italy, and an Alexander von Humboldt Fellow of Germany. In addition to his scientific pursuits, he is engaged in social work and is the president elect of the Lions club of Kandy, Sri Lanka. Recently he was appointed as the chairman of the Sri Lanka Pugwash Council, whose members seek peaceful and cooperative solutions to armed conflicts and other global problems.



CREDIT: CHANDRA DISSANAYAKE

All essays appearing and interactive features in this series can be found online at www.sciencemag.org/sciext/globalvoices/

Fluoride in Drinking Water—Friend or Foe?

The link between the fluoride geochemistry of water in an area and the incidence of dental fluorosis, a tooth-damaging condition, is a well-established relationship in medical geology. Although the value of limited exposures to fluoride for human health, particularly for dental health, is well known, higher exposures in many tropical lands where fluoride is found in excessive quantities in the drinking water have devastating effects. As in the case of some essential trace elements, the optimal level of fluoride varies within a narrow range. In locations where the exposure to fluoride is not well controlled, including my home country, Sri Lanka, many people suffer from a fluoride imbalance. While carrying out detailed research on the medical geology of dental fluorosis in Sri Lanka, I have seen firsthand how disfiguring this condition can be.

When the fluoride content of the drinking water exceeds about 1.5 mg/liter, the maximum concentration recommended by the World Health Organization, and when such fluoride-rich water is consumed, particularly by children under 7 years of age, the teeth develop a dark brown coloration and a mottling. This condition is known as dental fluorosis (see the top figure). Although not a life-threatening condition, it constitutes a massive social problem, particularly for girls worried about their marriage prospects. Some use sand paper to brush their teeth with the hope of getting rid of the ugly stains.

Sri Lanka, an equatorial developing country with a population of about 20 million, has well-defined dry and wet zones. In the dry zone, dental fluorosis is highly prevalent, and a population of more than 2 million is at risk of developing it.

Most Sri Lankans live in close association with their immediate geological environment, and only about 30% have clean piped water with controlled mineral content. The rest generally get their drinking water from wells. In some dug wells, and most notably in deep boreholes, the fluoride concentration in water exceeds 1.5 mg/liter. In some cases, the concentration can be as high as 10 mg/liter. The sources of the fluoride are the high-grade metamorphic rocks in the dry zone of Sri Lanka. These rocks include an abundance of fluoride-bearing minerals such as mica, hornblende, and fluorite. With funding from the Natural Resources Energy and Science Authority of Sri Lanka, I was able to produce a map for Sri Lanka showing the fluoride-rich zones and their potential impact on dental health (see the bottom figure).

From a strictly scientific perspective, one of the most interesting aspects of these studies is the biomineralogy of tooth enamel and the process by which hydroxyapatite, the



Dental danger. Geochemists studying the quality of water in a well in the dry zone of Sri Lanka. (Inset) Teeth from a patient with dental fluorosis in Sri Lanka.

primary mineral in teeth and bones, transforms into fluoroapatite when fluoride ingestion is excessive.

The "Geochemical Disease": Iodine Deficiency

It has been estimated that nearly 30% of the world's population is at risk for some form of iodine deficiency disorder (IDD). Insufficient intake of iodine is the world's most common cause of mental retardation and brain damage with 1.6 billion people at risk, 50 million children already affected, and 100,000 more adding to their ranks every year.

IDDs are particularly severe in tropical regions. The resulting large populations of people with impaired mental function have serious direct and indirect impacts on all aspects of life in these places.

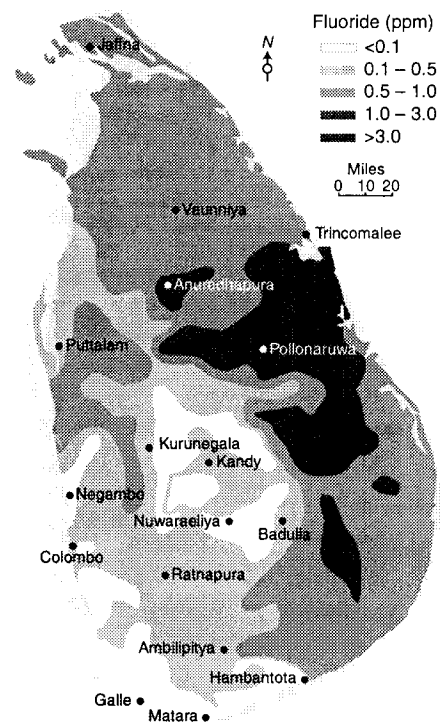
The geochemistry of iodine and its chemical species has a marked influence on the prevalence of IDD, including endemic goiter (see figure on the next page). Collectively, these IDD are often referred to as "geochemical diseases" in view of their etiology in the geological environment. The sea is a major source of iodine, so there often is a relationship between the incidence of IDD in a region and that region's distance from the sea. In general, the farther away from the sea, the less iodine is available. Other factors such as atmospheric circulation, however, may play a role in iodine availability, as does topography. In many mountainous regions, for example, iodine abundance is quite low, with a concomitant increase in IDD.

Humic substances rich in organic matter in the environment also are known to play a major role in the speciation and geochemical mobility of chemical elements such as iodine. The in-ground conversion of chemical species into toxic or nontoxic forms has important implications for the health of individuals living in a particular geochemi-

cal habitat. Iodine is strongly fixed by humus, and soils rich in humus therefore tend to be rich in iodine. However, the bioavailability of that iodine, which depends on the pH conditions, often is very low. Because iodine is strongly fixed by clay and humus, these materials may function as "geochemical goitrogens," particularly in the tropical environment. Interestingly, in the Kalutara district—an area close to the sea on the west coast of Sri Lanka (and therefore only minimally affected by last December's tsunami)—the endemic goiter rate is high despite the proximity to the sea. This clearly supports the hypothesis that the environment contains goitrogens, which trap the iodine and make it far less available to the people living in the area.

Eating Clay

The habit of eating soil and the physiological effects of its ingestion are a fascinating field of study. This seemingly repulsive phenomenon enables researchers to study the direct link between soil chemistry, soil mineralogy, and health.



Fluorine island. Map showing in Sri Lanka.

CREDIT: (TOP) CHANDRA DISSANAYAKE

Geophagy is defined as the deliberate and regular consumption of earthy materials such as soils, clays, and mineral substances by humans and animals, among them elephants, monkeys, chimpanzees, gorillas, birds, reptiles, and horses. In some cases, animals eat pebbles and rocks that serve as mechanical aids to digestion, for grinding food into bits.

The practice of geophagy by humans has been observed on all continents, although it is most commonly seen in the tropics, and particularly in tropical Africa. It is especially common among pregnant women.

Alexander von Humboldt, who explored South America for its natural resources, observed the practice of geophagy during his expeditions to Orinoco in Venezuela in the period from 1799 to 1804. The Ottomac people, who practiced geophagy there, apparently did not eat every type of clay, but chose only those clays that were most "unctuous and smoothest to touch." Interestingly, the Ottomacs did not suffer health problems as a result of their clay eating, yet other tribes who ate different soils did become sick.

This early observation by von Humboldt generated considerable interest among medical scientists years later. The debate about the possible benefits of eating soil continues today.

Why do humans and animals consume soil? Could it be that inorganic nutrients in the soil supplement our dietary intake of essential trace elements? Does the ingestion of soil cause detoxification of noxious or unpalatable compounds present in the diet? Do these soil elements alleviate gastrointestinal ailments? These questions need to be answered, and further detailed research will be needed to understand the strange phenomenon of geophagy.

Is Hard Water Good for Heart Ailments?

One of the most tantalizing geology-health correlations involves the incidence of cardiovascular diseases (CVDs) and the water hardness of a particular area. In several countries and regions, a negative correlation between water hardness and deaths due to CVD has been observed. This correlation has been seen in both temperate and tropical countries. Even though a causal effect still cannot be ascribed to this geochemical correlation, the potential role that trace elements in drinking water could play in this relationship has aroused considerable curiosity among medical geologists.

If we accept for now that there is some causal basis to this correlation, then the question to ask is this: What is it in the hard water that is cardio-protective?

Mounting evidence from many studies indicates that this "water factor" is magne-

sium, with calcium playing a supportive role. The presence of calcium and magnesium in natural water results from the decomposition of calcium and magnesium aluminosilicates, which derive from limestone, magnesium limestone, magnesite, gypsum, and other minerals.

An important point to note is that only two out of every three studies on this topic have shown a correlation between cardiovascular mortality and water hardness. Studies probing the effect of water magnesium alone have all shown an inverse correlation between cardiovascular mortality and water magnesium level—the more magnesium, the lower the rate of CVD mortality.

Even though medical geologists have shown much enthusiasm for the possible cardio-protective role of magnesium, those in the medical profession are yet to be fully convinced of the hard water-CVD connection. More research is needed to clearly pinpoint the elusive "water factor," if indeed there is one to be found.

The Radiation Paradox

Natural radioactivity on Earth has been in existence since the planet formed, and there are about 60 radionuclides present in nature. These are found in air, water, soil, rocks and minerals, and food. About 82% of this environmental radiation is from natural sources, the largest of which is radon.

Some areas of the world, called high background radiation areas (HBRAs), have anomalously high levels of background radiation. In such terrains, the geology and geochemistry of the rocks and minerals have the greatest influence in determining where the high natural radiation shows up. Extreme HBRAs are found in Guarapari (Brazil), southwest France, Ramsar (Iran), parts of China, and the Kerala coast (India). Of these, most are found in tropical, arid, and semiarid areas. In certain beaches in Brazil, monazite sand deposits are abundant. The external radiation levels on these black beach sands range up to 5 mrad/hour, which is nearly 400 times the normal background level in the United States. The Brazilian coastal sands have several radioactive minerals, among them monazite, zircon, thorium, and niobate-tantalate, as well as nonradioactive minerals, including ilmenite, rutile, pyrochlore, and cassiterite.

In India, along the 570-km-long coastline of Kerala, there are major deposits of monazite-rich mineral sands with very high natural radiation. The monazite deposits are larger than those in Brazil, and the dose from external radiation is, on average, similar to those reported in Brazil.

Ramsar, a city in northern Iran, has one of the highest natural-radiation levels in the world. In some locations at Ramsar, the radiation level is 55 to 200 times higher than the background level. Values as high as 260 mGy year have been recorded in Ramsar. The unit of ionizing radiation here, grays per year, corresponds to 1 J of energy imparted to 1 kg of tissue (the milligray, mGy, which is one-thousandth of a gray, is more commonly used). Whole-body exposure to a uniform dose of 3 to 5 Gy would kill 50% of those exposed within 1 or 2 months.

The most interesting feature in all these cases is that the people living in these HBRAs do not appear to suffer any adverse health effects as a result of their high exposures to radiation. On the contrary, in some cases the individuals living in these HBRAs appear to be even healthier and to live longer than those living in control areas that are not classified as HBRAs. These phenomena pose many intriguing questions for medical geologists.



Woman with endemic goiter.

Breaking Barriers

The examples that I have outlined here illustrate that geology is no longer confined to

the study of rocks and minerals. I suspect that as the field of medical geology becomes better known, the medical community will discover that geology could play a major role in the etiology of a variety of diseases. Uncovering these relationships is an inherently multidisciplinary task. After all, for medical geology and geochemistry to be of use to the public and to health authorities of a given region, all samples from the local environment—that is, rock, soils, water, plants, and food—need to be studied together and correlated with *in vivo* studies.

In the medical field, too, as discoveries are made in the physiology and metabolism of trace elements, the biochemical mechanisms underlying the body's absorption and rejection of trace elements, and the cellular mechanisms that regulate these processes, researchers may also find a greater need for the understanding of geology and trace-element geochemistry.

Geology and medical science, disciplines that until now have been considered poles apart, may now find themselves joined into a multidisciplinary framework for unraveling some of nature's most interesting secrets.

The author is at the University of Peradeniya, Peradeniya, 20400 Sri Lanka. E-mail: cbdissa@hotmail.com

10.1126/science.1115174