THEORETICAL BASIS FOR MEDICAL GEOLOGY

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Abstract

Medical Geology is fast becoming a discipline in its own right by filled the vacuum between the evidently critical intersection between the earth system and health problems in man and other biota. Scientist have began to assess the long acknowledged but under-explored impact of natural and anthropogenic earth science factors on health in an effort that has also pulled in other disciplines that is establishing the link between man and his habitat the Earth. With the progress made the there are calls that the time has come to move towards laying a theoretical base for the discipline, as all individual disciplines require. This paper proposes the concept of stewardship as the underpinning of Medical Geology and suggests a scientific framework for its operational theme and focus.

INTRODUCTION

The genesis of what has evolved into Medical Geology can be traced back to the realization of the environmental factor as one of the causal factors affecting health although, according to Finkelman *et al.* (2001), the impacts of geologic materials on human health have been recognized for thousands of years. This developed in response to apprehension of environmental degradation arising out of anthropogenic impacts resulting from industrial technology. *Silent Spring* (Carson, 1962) is the earliest expression of this apprehension has come to be defined by the health and environment cause-effect framework given in Fig. 1 below by WHO (2000).

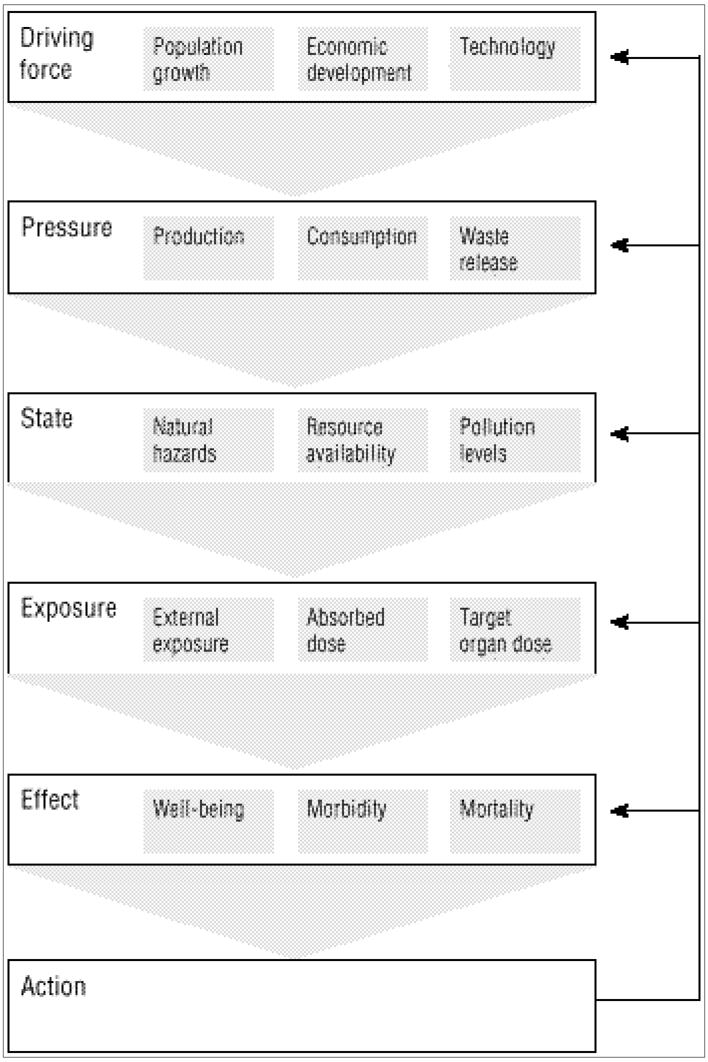

Fig. 1 Health and environment cause-effect framework (WHO, 2000)

These adverse or toxicological effects on health from the environment arise from poor air, water and soil quality as a result of contamination. In fact, the emergence of toxicology as an independent scientific discipline is a result of the effects on health from the environment. Natural materials also form the foundation of modern civilization and are crucial for almost every aspect of modern living. This interaction with natural materials is often viewed as harmless (Finkelman *et al*., 2001). However, some geologic materials pose significant health risks that jeopardize individuals, communities and even whole populations (Geotimes Staff, 2001)

Therefore, health effects, indicated by changes in longevity and functionality, arising from the environment imperatively require environmental stewardship through the study of earth materials and processes. In fact, Time magazine wrote in January 1989 that humans were threatening the state of the Earth's environment and declared it an endangered planet which making it more exigent on medical geology to supply solutions to health treats. The assessment of the influence of natural and anthropogenic earth science factors, according to Centeno *et al.* (2003), on the geographical distribution of a wide range of human and animal diseases has commenced.

MEDICAL GEOLOGY AS ENVIRONMENTAL STEWARDSHIP

In traditional medical practice, according to by Moeller (1997), physicians deal with patients according to the model given in Fig. 2. In this clinical interventional model the intercession comes in the diagnosis and treatment of a disease to cure the patient. This affords intervention but no control over the disease to enable elimination of its source or cause before infection.

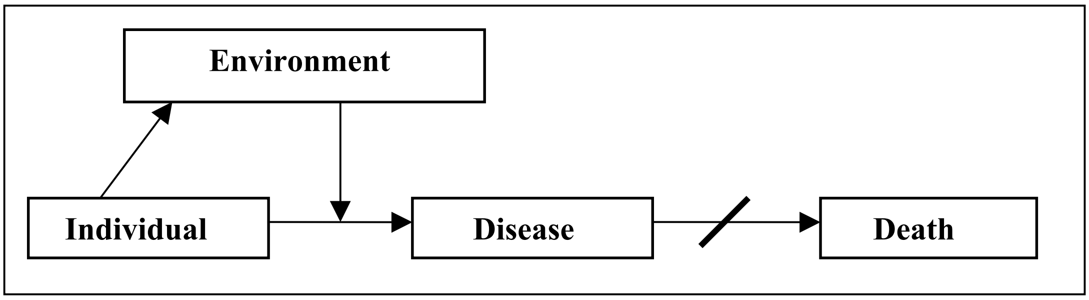

Fig. 2 Clinical interventional model

The environment health stresses need to be tackled to enable a measure of control of diseases arising from environmental factors. Traditionally these pre-emptive measures are taken under public health [branch of medicine dealing with safeguarding and improving community health through organized community effort involving prevention of disease, control of communicable disease and health education (Academic Press Dictionary of Science Technology)] including epidemiology. Moeller (1997) describes this practice according to the model given in Fig. 3.

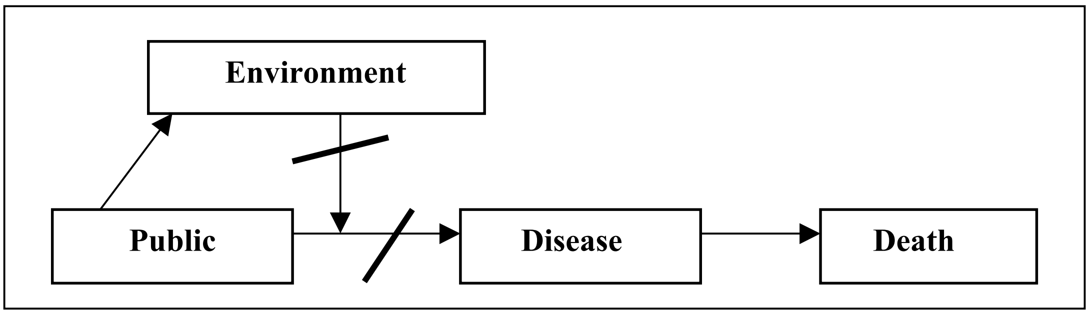

Fig. 3 Public health intervention

Public health intervention seeks to establish some degree of control over sources of risks to human health and well being. However, this does not afford sufficient control as the causes and sources themselves are not addressed. The ability to exercise greater control lies in the field of environmental health which is defined by Pew Environmental Health Commission (2001) as comprising those aspects of human health, including quality of life, that are determined by interactions with physical, chemical, biological and social factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling and preventing those factors in the environment that may adversely affect the health of present and future generations. This control according to Moeller (1997) is as in Fig. 4.

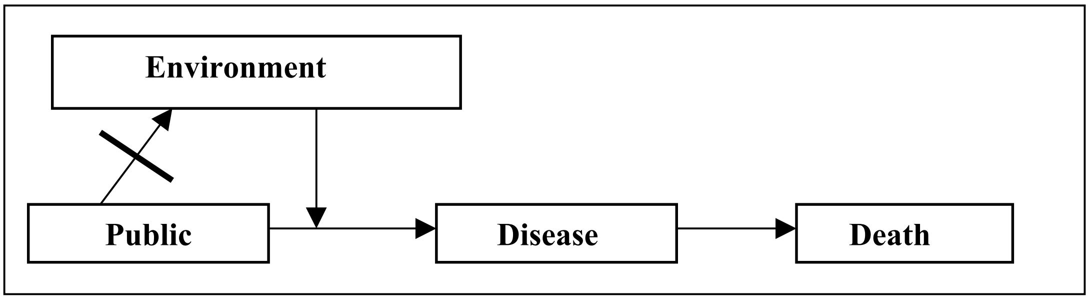

Fig. 4 Environmental stewardship

Environmental stewardship prevents environmental degradation and consequences for human health. The advantages are obvious as it reduces the risk factors in the environment. Medical Geology is concerned with the materials affecting public health and processes responsible for their behavior and distribution encompasses environmental stewardship.

Stewardship represents the underpinnings of Medical Geology which that also needs to be cast in a scientific and academic framework. An outline this is proposed below.

MEDICAL GEOLOGY CONCERN IN UNDERSTANDING EARTH SYSTEMS FOR STEWARDSHIP

The Earth System

A system is defined as a set of objects with relationships between them and their attributes or also as a set of interdependent elements forming a collective entity. The Earth may be considered as a system and the components and their interconnections are shown in Fig. 5 below.

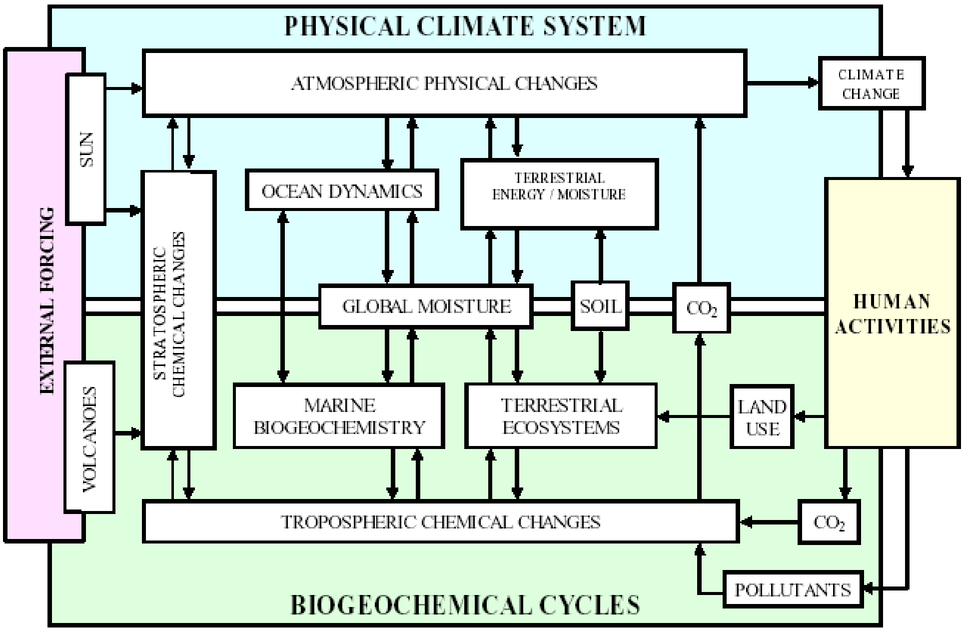

Fig. 5 The Earth System
Source: http://www.schools.ash.org.au/paa/EBpdfs/EB.IM1.IL.pdf

The understanding of this Earth System is sought for the purpose of intervention and control in order to prevent or intervene to arrest menace to public health. This involves the characterization and clarification of the components and processes achieved through the earth sciences which are directed towards environmental stewardship. Medical Geology is concerned with the understanding of how the geological, physical and biological processes of the Earth System are functionally interrelated including the geological-physical-biological interactions.

The Source-Pathway-Target Concept.

The effective practice of environmental stewardship using the Source-Pathway-Target concept (Holdgate, 1979), as shown in Fig. 6, requires erecting impedance between the Source, Pathway and Target for intervention and control as shown in Fig. 7.

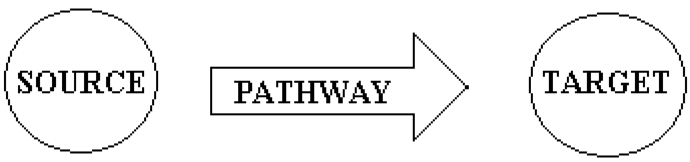

Fig.6 Source-Pathway-Target Analysis Model

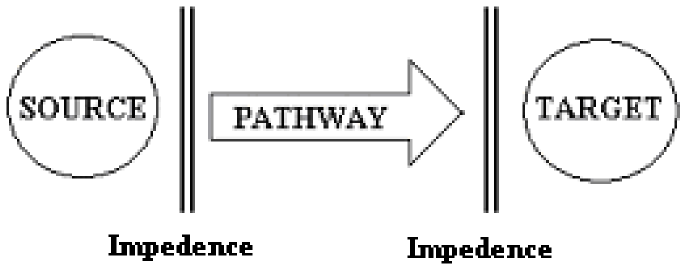

Fig. 7 Source – Pathway – Target Impedance

Medical Geology aims at proving this stewardship in insuring that the source of harmful materials is capped. It does seem paradoxical to have clinical or public health intervention, as mentioned above, when the source is not controlled. This assures optimum intervention and control that lies in ensuring that the source, in the first instance, does not emanate harmful materials and the pathways available, secondarily, are checked.

THE MEDICAL GEOLOGY APPROACH TOWARDS STEWARDSHIP

Human existence is embedded in the Earth System along with its composition and workings. The vast array of processes and transformations among solid, aqueous and gas phases with the participation of living organisms encompassing the Earth System forms the milieu for human interaction with the system. The approach of Medical Geology involves the study of the materials and their reactions, transport, effects and fates. This requires a two-prong approach in understanding the respective components and the processes constituting the interactions between these.

Aspect One: Components of the Environment

One aspect involves understanding the components of the Earth System i.e. rocks, soils, waters and the atmosphere. This involves the solid or terrestrial Earth or *geosphere/lithosphere*, the aqueous layer or *hydrosphere,* the gaseous cover or *atmosphere* and the *biosphere* consists all of the living things on Earth as depicted in Fig. 8. The biosphere along with the other three spheres forms the ecosystem.

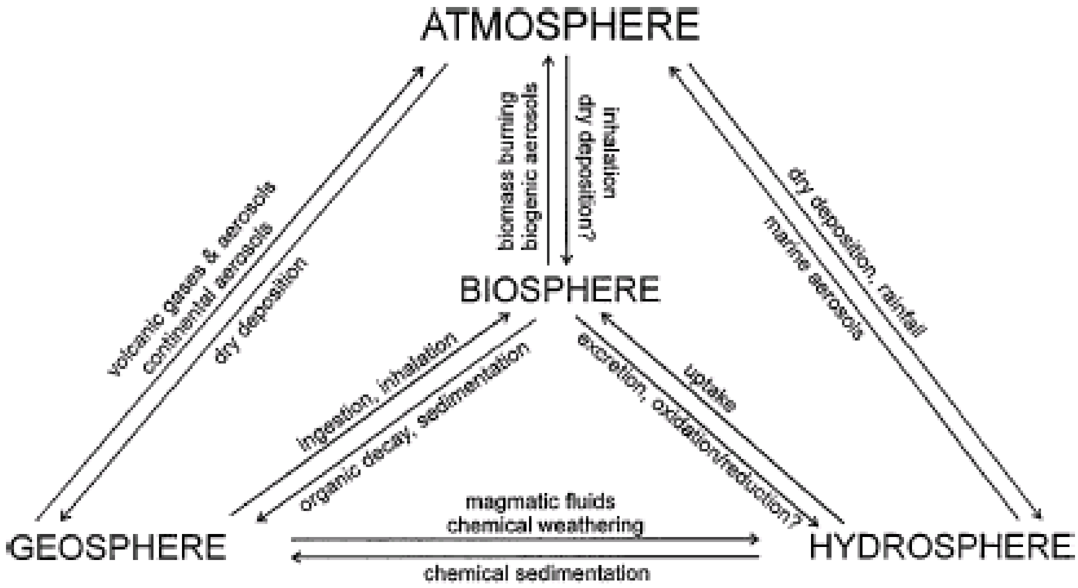

Fig. 8 Components of the Earth System
(Diagram from Larocque and Rasmussen, 1998)

The geosphere is the original source of all matter except that added from space in the form of meteorites and cosmic dust but inputs and escape of elements subsequent to their assemblage on Earth have been relatively unimportant. The geological mapping and identification of rock types and minerals, hydrogeological investigations and rock-fluid interactions are critical areas in the study of the Earth System components.

Aspect Two: Processes of the Earth System

The next stage involves understanding the processes in and between the different environments. There is a continuous exchange of matter and energy through interactions and processes transferring these between the geosphere, hydrosphere and atmosphere as shown in Fig. 9.

Fig. 9 Schematic overview of the interactions in the environment
Source: http://www.mpimet.mpg.de/working_groups/wg4/

This results in numerous processes occurring out there. The processes, behavior and mobilization of materials including elements and chemical species are dependent on the physio-chemical conditions existing in the environment, as well as, their respective nature. As Fig. 9 shows there are processes are occur within the individual components and across the component interfaces involving two or more components.

The investigation of the respective components i.e. rocks, soils, ground waters, surface waters and atmosphere and the interactions of the environment involves studying these at various scales from the megascopic to the microscopic (a new research area called environmental molecular geochemistry). This also involves the study of natural systems and perturbed systems with the latter compared to the former.

A. Macro-Level Processes

A.1 Processes in Natural Systems

There are many processes at work. These include the rock cycle and the hydrological cycle to mention two. Each of these is formed from numerous processes. These natural processes involve the creation, modification and destruction of the different states of matter. Materials are also exchanged between the atmosphere, hydrosphere, geosphere and biosphere. An example is the geochemical cycles i.e. the pathways tracing the storage and exchange of chemical elements between the atmosphere, hydrosphere, geosphere and biosphere. The Carbon Cycle in Fig. 10 illustrates sinks and processes involving transport mechanisms and transformation of material in natural systems.

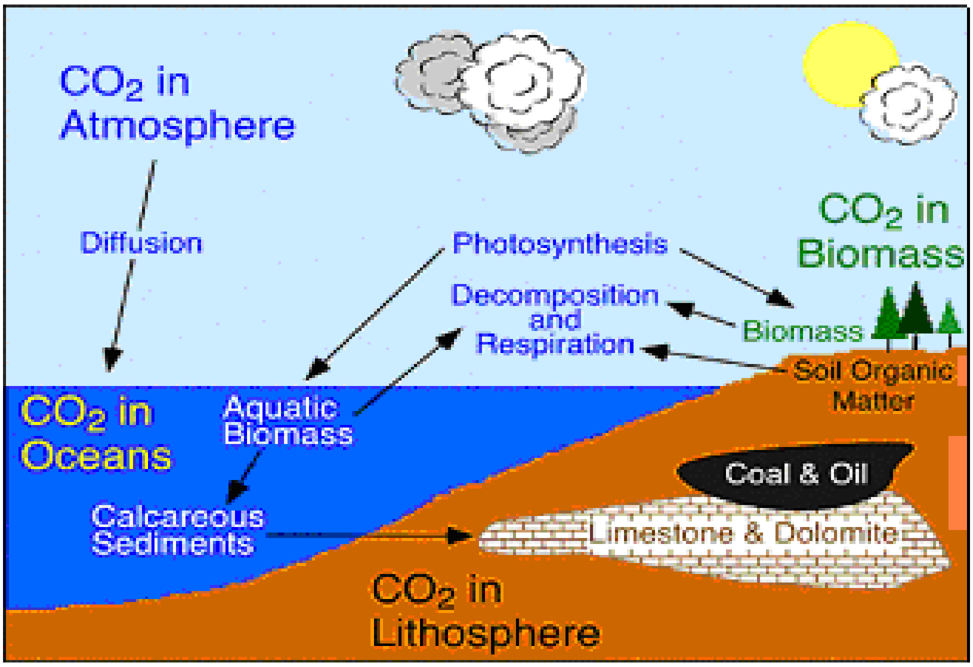

Fig. 10 The Carbon Cycle
Adapted from http://www.geog.ouc.bc.ca/conted/onlinecourses/geog_210/210_2_7.html

A.2 Processes Causing Perturbed Systems

Time magazine (January 1989) says that the biosphere, atmosphere, hydrosphere and are currently being altered at rates far surpassing the natural processes. Perturbed systems are consequence of this alteration and embody the consequences of human induced forcing of the natural system. This has resulted from global warming, acid rain and acid mine drainage and long range transport of materials amongst others.

Global Warming: An example of human activities is the release of gases like CO_2 into the environment illustrated using the Carbon Cycle in Fig. 11 causing a change in the cycle of this element.

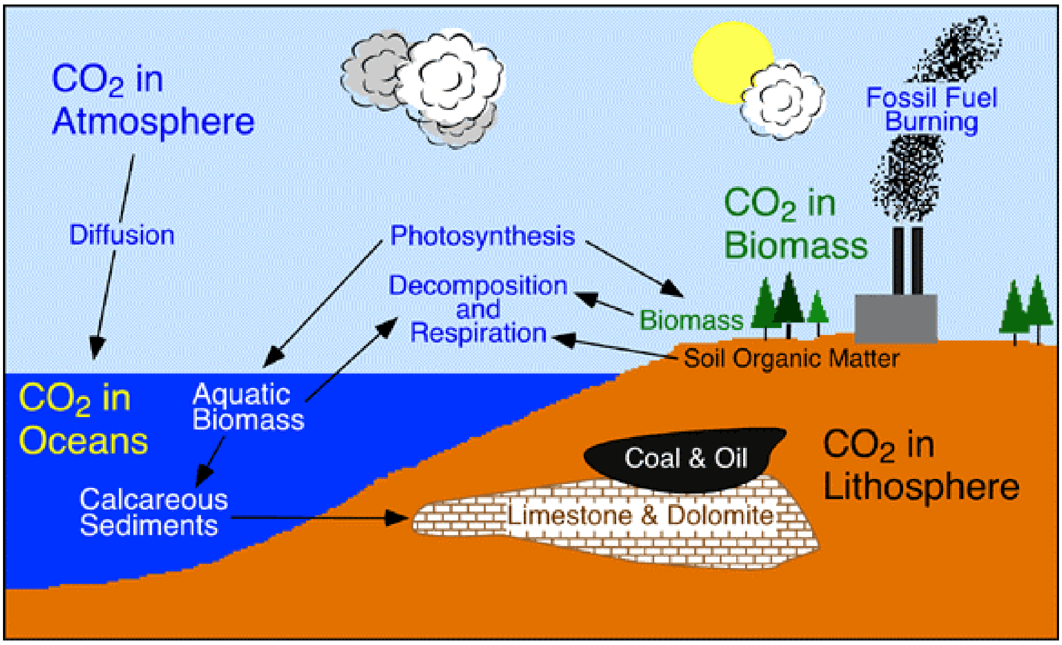

Fig. 11 The Perturbed Carbon Cycle
Source: http://www.geog.ouc.bc.ca/conted/onlinecourses/geog_210/210_2_7.html

CO_2 and certain other gases such as H_2O in the atmosphere called the greenhouse gases interact with incoming energy from space by absorbing and reemitting it back to maintain atmospheric temperatures alike a greenhouse sustains temperatures. An increase in the amount of greenhouse gases increases the amount energy retained as the more is absorbed causing the atmospheric temperature to rise as shown in Fig. 12 below.

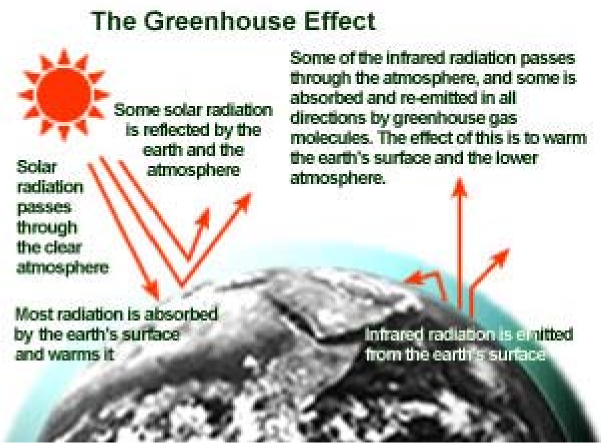

Fig. 12 The Greenhouse Effect
Source: http://www.epa.gov/globalwarming/climate/index.html

The increased temperatures cause environmental changes affecting global weather patterns causing change in climatic systems.

Acid rain: Acid rain consists of acids from the atmosphere that fall dissolved in rainwater as shown in Fig. 13 below. Gases like SO_2 and NO released into the atmosphere react with H_2O, O_2 and others resulting in mild acid solutions which precipitate as rain affecting plants and animals.

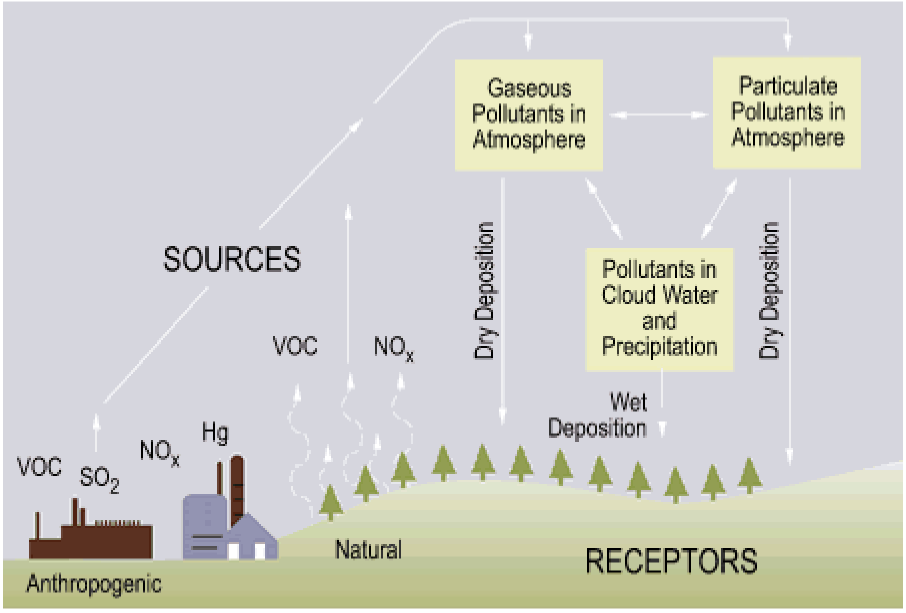

Fig. 13 Acid Rain
Source:http://www.epa.gov/airmarkets/acidrain/index.html

Acid Mine Drainage: This is a highly acidic drainage flowing from mine edits or waste piles with high concentrations of dissolved metals formed by geochemical reactions occurring due to the exposure of the mineral pyrite to air. The metals stay dissolved in solution until the pH rises to a level when they precipitate as bright orange colour precipitates as seen in Fig. 14 below.

Fig. 14 Acid Mine Drainage
Source: Dept. of Environmental Protection, Commonwealth of Pennsylvania, U.S.A.
(http://www.dep.state.pa.us/dep/deputate/minres/bamr/amd/science_of_amd.htm)

The understanding of the geology of mineral deposits and geochemical processes responsible for elemental mobility is necessary to overcome health impacts of the development of mineral resources.

Long-Range Aerial Transport: The atmosphere is a conduit of material and has come to lift and transport dust, toxic chemicals and microorganisms. Griffin *et al.* (2002) give an account of the global transport of dust, toxic chemicals and microorganisms in the atmosphere.

B. Micro-Level Processes

This involves looking at specific materials or processes involving particular earth materials or specific pathways. Environmental media like surface and ground waters due to their dissolution of rocks and soils upon contact (Gough, 1993) are pathways for geochemical element mobility. Mass-Transport processes like advection, dispersion and diffusion that move matter through the air, surface water or in the subsurface environment are investigated. These vast array of chemical processes and transformations among solid, aqueous and gas phases (with the participation of living organisms) are controlled by microscopic-scale reactions occurring primarily at the surfaces of solids and their interfaces with aqueous solutions or with air. The interactions and interfaces are important because it involves dissolution releasing chemical species into solution or vice-versa. An important surface phenomenon of immense environmental importance is adsorption, which is the accumulation of atoms and molecules on surfaces.

The investigation of the sources, pathways and targets of specific heavy metals and essential trace elements or trace elements (termed so according to conventional geochemical division of elements as major, minor and trace elements as a function of their relative abundance) is the domain of micro-level processes.

C. Earth System Components and Processes and Medical Geology

One of the main treat from earth system components and processes is pollution and ecotoxicity. Climate. Pollution, defined by the Academic Press Dictionary of Science and Technology, is any alteration of the natural environment producing a condition that is harmful to living organisms. Pollution is due to contamination i.e. the addition of any undesirable substances into any components of the Earth System. The pollutants can be gaseous, liquid or solid and come from natural, as well as, anthropogenic sources. Atmospheric pollution occurs when the concentrations of certain substances increase to a level to cause the air to become toxic. Water pollution occurs by the degradation in water quality that is quantified by biological, chemical and physical criteria. Water includes surface as well as groundwater. The quality of water desired depends on the intended use or its impact so the quality is specified according to the standards required for intended use and effects on public health or impact on the environment.

Investigations into minerals like asbestos illustrates the effects on human health. Inhaling asbestos can cause deleterious health effects like asbestosis (a fibrosis of the lungs), lung cancer and malignant mesothelioma (Finkelman *et al*., 2001). These include the serpentine mineral chrysotile, the most commonly used, and the asbestiform varieties of several of the amphibole minerals, including grunerite, known commercially as amosite); reibeckite, known as crocidolite, or blue asbestos; anthophyllite, tremolite; and actinolite. Chrysotile asbestos, for example, is commonly regarded as being less carcinogenic than amphibole asbestos. Other studies include the effects of coal combustion (Finkelman *et al*., 2003), environmental fibrous material (Hillerdal, 2003), geochemistry and vertebrate bones (Skinner, 2003).

The use of heavy metals goes back a long time. Eaton and Robertson (1994) and Silver and Rothman (1995) cite early uses like the use of lead in plumbing and to improve the taste of wine, lead arsenate as a pesticide and mercury as a salve to alleviate teething pain in infants. The anthropogenic contributions of heavy metals into natural systems have been increased phenomenally since the Industrial Revolution. Nriagu (1996) has demonstrated the exponentially increase in the production of heavy metals such as lead, copper and zinc between 1850 and 1990. The fate of heavy metals, like As, Cd, Hg and Pb and others, in the natural environment is of great concern due to their potential harmful effects (Adriano, 1986 and Alloway, 1995).

The deficiencies, excesses or imbalances of chemical elements also have a significant bearing on health. Examples of earth materials include essential and toxic elements are shown in Figure 15.

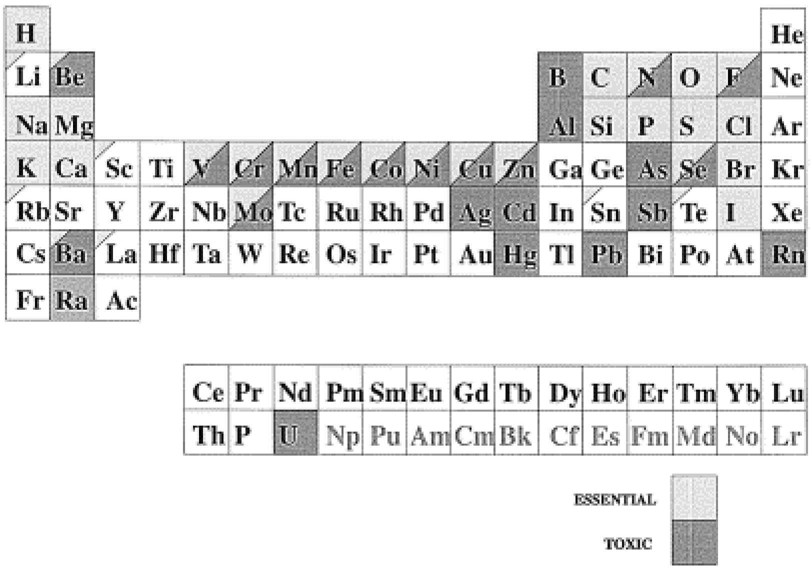

Fig. 15 The periodic table showing essential and toxic elements

Some elements are both essential and toxic. Elements that are possibly essential are indicated in a lighter gray shade. (Source: British Geological Survey, UK).

Typical concentrations of essential and toxic elements in ground waters are as in Fig. 16.

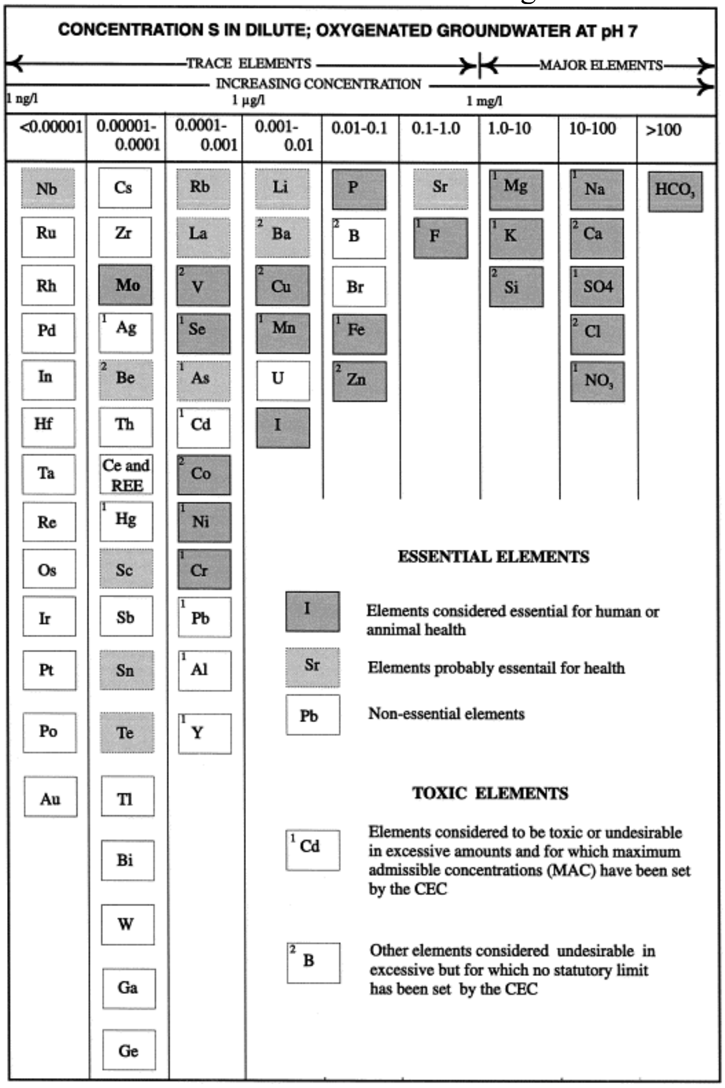

Fig.16 Elements in groundwater and their health significance [after Dissanayake and Chandrajith (1999) and Edmunds and Smedley (1996)].

According to Edmunds and Smedley (1996) the natural geochemistry of groundwaters and surface waters from interaction with rocks, also creates widespread health and acceptability problems in many parts of the world on a regional scale. The case of the arsenic problem in Bangladesh is well known (Smith *et al.*, 2000).

The process operating in natural and perturbed systems have an impact on health especially those involved in transport and dispersal of the components mentioned above. Some of the incidents are as follows. Naturally occurring processes e.g. erupting volcano emitting sulfur dioxide have an effect on health. Sutton *et al.* (2003) give an account of the health hazards caused by volcanic air pollution in Hawaii. Derbyshire (2003) relates about Natural dust and Pneumoconiosis in High Asia while Grattan *et al* (2003) reports on human sickness and mortality rates in relation to the distant eruption of volcanic gases. Other examples of natural sources are forest fires, dust and pollen.

Perturbed Systems usually result from to the negative effect of anthropogenic activities e.g. exhaust emissions, oil spills, dumping of wastes in water, overuse of pesticides and chemical fertilizers, improper disposal of wastes and so on. The anthropogenic sources of pollutants are emissions from industry, transportation, power generation and open burning. The varieties of materials that may pollute water are very vast. Soil pollution occurs when these become sinks for substances that are pollutants. Sorption processes determine the retention of contaminants in soils. The emergence of contamination land is an outcome of soil pollution and pose threats to human health, animals, plants and the ecosystem. As a example of the integrated pollution effects Naidu and Nadebaum (2003) relate on the geonenic arsenic and associated toxicity problems in the groundwater-soil-plant-animal-human continuum.

The consumerist and industrialized society generates a large quantity and variety of solid waste. The composition of waste is very heterogeneous, which includes plastics, paper, glass, wood, metals and textiles. In short, it is anything that is discarded. Sources of wastes are equally large and varied such as industry, commercial undertakings, agriculture, mining and domestic homes. These waste are hazardous as they have the propensity to release pollutants into the environment. Hazardous waste is any discarded substance that possesses any of the following four characteristics – reactivity, corrosivity, ignitability or toxicity (or is carcinogenic/mutagenic/teratogenic). Wastes disposed on land, one of the oldest methods of disposing wastes, allow toxic materials to leach into the subsurface, release odors into the atmosphere apart from attracting pests and incubating diseases. Incineration releases pollutants like metals, gaseous oxides (nitrogen oxides and sulfur dioxide) and other materials into the atmosphere. Nowadays dumps have been replaced by planned landfills where the waste is deposited in a designed pit and then covered.

As the understanding of the workings of the environmental advances it naturally also assists in the effort towards countering perturbation. However, it has to be mentioned that the crusade against instances of perturbation like pollution is a major impetus in advancing this discipline.

Tools form new technologies and the advancement of analytical capabilities play a critical role in Medical Geology. Johnson (1997) very truly states that little awareness of environmental impacts or development of the geochemical concepts could have happened without major advances in the analytical capabilities for measuring low levels of metals and organic chemicals in water. She goes on to say that the technological advancement in instrumentation was led by refinement in atomic adsorption spectrophotometry (Mancy, 1971). It was successful because of its speed, low cost, simplicity and had little interference from the water matrix or solution that was being analyzed. The analysis of organic compounds has been facilitated from the early 1970's with advances in computer-assisted gas chromatography/mass spectrometry (Keith, 1976).

ASPECT THREE: MATERIALS AND ECOTOXICOLOGY

The third aspect involves ecotoxicity dealing with the adverse effects of toxic materials on natural systems and evaluates their potential impact. A background level represents natural concentrations so background values of an element or chemical species are those that occur naturally in the environment and those in concentrations above background values are considered as contaminants. When elements or chemical species occur at levels that are potentially harmful than they are labeled as pollutants or hazards. Examples of toxic elements that have considerably studied are mercury, arsenic etc. The forms or speciation of these elements and compounds is important as it determines the bioavailability i.e. its uptake and incorporation into animal and plant tissue. Examples of toxicity effects are the nulear accumulation of Hg in neutropil granulocytes associated with exposure from dental amalgam (Lindvall *et al*., 2003), minerals in human blood vessels and their dissolution *in vitro* (Pawlikowski, 2003) and effects of enhanced zinc in drinking water on brain and memory (Jones *et al*., 2003)

ASPECT FOUR: COLLECTIVE ANALYSIS OF THE FACTORS

The fourth aspect involves the collective analysis of the diverse factors. The different factors have to be studied in concert to gain a holistic understanding of the suitability of an area. An important tool in this is analyzed with geographical information systems as their geographic dimension enables their manipulation in the form of spatial data and allows spatial information from diverse disciplines to be collected and analyzed simultaneously. This spatial data, for example, may be conceptualized using one of the approaches mentioned by Quiroga *et al.* (1996) i.e. the categorical approach to define specific relationships amongst the different categories each forming a data layer. The demarcation of spatial risk zones based on concentration levels of essential and toxic elements compiled with geological and epidemiological information represents a very portent tool for chemical element–health links with the utilization of Geographical Information System (GIS) techniques.

CONCLUSION

The thrust of Medical Geology is to provide stewardship to will prevent and, optimally, eliminate the treat to health from the Earth System. This is the underpinning of the endeavors towards uncovering the effect of the Earth System on health especially its perturbation due to anthropogenic forcing. This involves looking at several aspects of the Earth System individually or simultaneously at various levels as mentioned above to understand them and their interactions to be able to achieve an integrated comprehension towards diagnosis and prognosis.

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