

MEDICAL GEOLOGY and ITS SIGNIFICANCE FOR TURKEY

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Medical geology is a branch of science that investigates the relationship between natural geological factors and health problems of humans, animals and plants or formation of such problems and the possible effects of geological environmental factors on the geographical distribution of health problems. Since it covers a very wide and complex area of research, it requires a multidisciplinary research in which researchers from different branches of science such as geologists, medical doctors, biologists, and veterinarians would participate.

While the effect of natural environmental factors and the use of environment on human health traces back to old civilizations of Rome and Peru - Inca, in the recent years, heavy metals and the associated adverse health effects have constituted a wide area of interest both in scientific studies and on media. Elements like arsenic, cadmium, mercury, and lead and heavy metals are among potential pollutants and such elements or heavy metals which depict high rates of existence in many countries (such as Bangladesh, China, India) have been the subject of many studies.

Especially the realization of the close relationship between geological environment defined with the help of geochemistry and human, animal and plant health led to the arousal of medical geology as a new branch of science and Medical Geology was described as “a branch of science dealing with the relationship between geological factors and health problems of humans, animals and plants” (Selinus, 2002; Finkelman and et. al. 2001).

History of medical geology

The relationship between geology and health has been known for thousands of years. Although physicists and philosophers in old Greece and China were aware of the effect of geology on health, modern medicine recognized just in the 19th century how necessary some elements are for health. Hippocrates (400 BC) who is regarded by many scientists to be the founder of medical geology noticed how environmental factors effected disease distribution (Lag, 1990; Foster,

2002). In the 3rd century BC, in China, it was found that Ag, Cu, Fe, and Pb would cause intoxication (Liang et al., 1998) and lung problems developed due to rock crushing and lead intoxication were realized. Roman architect Vitruvius (last century BC) saw the health effects that could be related with mining and drew attention towards the hazards which would be caused by the water around mines and environmental pollution (Nriagu, 1983). Lead was produced approximately 5000 thousand years ago in Copper, Bronze and Iron Ages progressively without the full awareness of its harms (Hong et al., 1994). Intoxications occurred as a result of intensive lead use have been found on clay tablets of Middle and Late Assyrians (1550 -600 BC) and on old Egyptian inscriptions (3000 years ago) (Nriagu, 1983). Elements such as As, Cu, Hg were used in Roman and pre-Roman periods. For instance, Hg, Ag and Au were widely used in relation to teeth during the whole Roman Empire, in the 12th century in Egypt, in the 16th century in Middle and South America (Eaton & Robertson, 1994; Fergusson, 1990). Arsenic was used by the old Greek, Roman, Arabs and Peruvians as poison besides for treatment purposes (Fergusson, 1990).

At the beginning of 1990s, fluorosis stemming from drinking water containing high fluorine was defined. Although normal fluorine amount is generally accepted to be between 0.1 and 1 ppm, this amount rises up to 40 ppm in places such as some regions of Africa, China and India and this leads to serious teeth problems and skeleton fluorosis (Selinus, 2002). In China, it was understood that disease experienced in 1930s was due to low selenium in the region (Selinus, 2002).

With the 20th century, the discovery of the connection between environmental factors and various diseases as a result of numerous studies have apparently displayed how important are trace elements with regard to human, animal and plant health.

Some approaches to medical geology

Medical geology requires understanding the operation of the system constituting the environment; such as rock, soil, water, atmosphere, and the interaction between them. Behaviors and mobility of elements and chemical materials are related to their nature and physical and chemical conditions of the environment they exist in. Investigation of parts such as rock, soil, surface water, underground water, and atmosphere and their interaction with the environment requires a very wide research from "micro" level (resources and targets of trace elements and heavy metals) to "macro" level (events in the natural system like rock cycle, hydrological cycle) (<http://www.medicalgeology.org/PDF/MedGeo.pdf>).

Approaches concerning the medical geology can be summarized as: 1) the study of foreign substances entering into body and the medium

they are entering, with petrographic and mineralogical methods; 2) the study of geological environment and its relationship with health and 3) the study of anthropogenic factors.

Minerals and mineral dusts: Minerals which are the main components of rocks and soil are inorganic solids of crystal structure, which came into being by natural ways. Minerals and their synthetic analogues are generally used as abrasive, as catalyst, in ceramics, as natural isolation material, ion-converter, molecular sieve, dye, construction material, in numerous and various industrial areas like pharmaceuticals. While being continuously exposed to minerals in daily life, it is known that some minerals cause various lung diseases like pneumoconiosis and cancer when taken by respiratory tract. Especially the epidemiological evidences from 1900s to 1960s have shown that breathing asbestos minerals causes fibrosis, lung cancer and mesothelioma. In addition, it has been realized that some other minerals can be potential toxins for lung and in 1940s, 1950s and 1960s observations led to numerous studies on pathology of diseases related to various mineral dusts (Guthrie & Mossman, 1993).

In troposphere and hydrosphere, there exist high amounts of dust of approximately 0.1 - 30 μm length, resources of which are various rocks on earth and which came into being naturally (Klein, 1993). Data on microscopic characteristics, morphology, general chemical composition, structure types, and the geological formation of minerals or mineral groups are very crucial in researches concerning mineral dusts. Morphological measurements include grain size, shape and tissue (the ratio of length to diameter and/or fibre-like structure) and are analyzed using optical microscope, Scanning Electron Microscope (SEM), Transmission Electron Microscope (TEM). The chemical composition is generally obtained with Energy Dispersive Spectroscopy (EDS) affiliated with TEM and SEM and the structural data, on the other hand, is obtained using TEM. Analytical Transmission Electron Microscope (ATEM) provides characterization of each dust from half-quantitative to quantitative with morphological observations and chemical analysis. In addition, Electron Probe Analysis, Analytical Electron Microscope, Particle Induced X-ray Emission (PIXE) and Secondary Ion Mass Spectrometry (SIMS) are methods used for finding mineral composition.

With the aim of answering the question: "What is the mechanism leading minerals to cause disease?", numerous studies on pathogenesis due to minerals were carried out in 1980s and 1990s (Guthrie & Mossman, 1993). In researches concerning this subject matter, biological, biochemical and pathological studies are crucial and any model to be constructed requires geological and geo-chemical studies because biochemical events occur on mineral surface or close to the mineral surface. Factors such as endurance, solubility, tensile strength, surface

relativity, surface structure, surface load, mineral composition and mineral structure are necessary in order to explain the various biological reactions of minerals related to their morphology.

Pathogenicity of minerals is related to their physical and chemical characteristics. Minerals are typically heterogeneous with respect to mineral content, mineral composition and/or mineral structure and this affects their biological characteristics. This heterogeneity may contain a significant part of the mineral; for instance, if the sample being worked contains 75 % clinoptilolite (zeolite mineral which is not fibre-like) and 25 % erionite (fibre-like zeolite mineral), the probability of this sample to cause mesothelioma will be much higher than another sample containing 100 % clinoptilolite. Besides this, even a very small heterogeneity significantly affects the characteristics of the sample being processed; for instance, it is argued that the small amount of asbestiform tremolite is the cause of mesothelioma among the workers of crysotile mine. While small amounts of metals affect the catalytic features of many zeolite minerals, small deviations in the ideal structure of the mineral may alter its electromagnetic characteristics (Guthrie, 1993).

Hazardous minerals and mineral dusts: Naturally formed dusts directly reflect the mineralogy of the medium. In terms of volume, the estimated percent of the minerals widely existing on the crust of earth is 92 % silicate minerals. Majority of the minerals are generally slender in granule or of equal size, some of them are layer-like, and some of them are short and thick than others. Mineral groups which are few and infrequent than the others pose hazard to health if they exist on very high concentrations within the dust in the medium and many of them have fibre-like structures. Some of such mineral groups are given below (Klein, 1993).

Amphibole group minerals generally display long prismatic or needle-like crystal structure and some may be asbestiform in infrequent geological formation. The complex chemistry of amphibole minerals is a result of the fact that they reveal very intense "solid solution". Riebeckite and its asbestiform type are among amphiboles rich in crocidolite sodium. Commercially used asbestiform amphiboles are crocidolite (similar to riebeckite in composition) and amosite (asbestiform type of grunerite). Amosite and crocidolite mineral names correspond respectively to brown and blue amphibole asbestos. When compared with crysotile, amosite and crocidolite, they are biologically resistant and biochemically more reactive in morphology and mineralogy (Gibbons, 1998). Amosite and crocidolite, even a very small amount of which is considered to be cancer producing are found more in banded iron deposits of Precambrian age in South Africa and less in west Australia and they pose a serious threat for health in South Africa (Gibbons, 2000). Other amphibole group minerals

that could be in the form of asbestiform are antofillite, tremolite and actinolite. Tremolite, on the other hand, in itself poses a great risk in mesothelioma formation.

Crysotile, is one of the three polymorph silica minerals together with antigorite and lizardite and they form serpentine group minerals. The main difference between these three minerals stems from their 1: 1 layer structure. These layers are plane-like in lizardite; 1: 1 layers are concentrically spiral, developing as narrow tubes parallel to x- axis in crysotile; 1: 1 layers are wavy and curly in antigorite. Crysotile which is defined as white asbestos in commercial terms forms approximately 95 % of all asbestos. Crysotile remains in lung for shorter than crocidolite, amosite, tremolite and in general exists with termolite in different ratios. Amphibole fibres are much more carcinogenic than crysotile (McDonald et. al., 1999; 2001). Absence of mesothelioma among workers of crysotile mines in South Africa is explained by the fact that these mines do not contain great ratios of termolite as the mines in Canada (Rees et. al., 2001).

Kaolinite, montmorillonite, vermiculite are among **other layered silicate minerals** widely found in soil, which are formed as a result of the chemical alteration of depth and mutation rocks; low degree mutation rocks, on the other hand, are talc schists, muscovite (serizite) schists and chloride schists. Many layered silicate minerals are of very small (μm level) grain size and in general they have flaky tissue.

Quartz and its microcrystalline type cort are the most commonly found **silica group minerals**. Quartz is very resistant both against breaking and against chemical break up and this characteristic makes it the most crucial component of soil, sand and gravels.

Only some of the **zeolite group minerals** (natrolite, chabazite, heulandite, and stilbite) are among the minerals forming rocks. Since there are too many cavities in the chassis structure of zeolites, they are intensively used in the industry. Many zeolites display layer-like, identical grain sized or fibre-like morphology. Only some infrequent zeolites (rodingite, mazite, erionite, and mordenite) have thin fibre-like tissue and their grains sometimes create hazard for health. Fach and his friends (2002) compared erionite and mordenite in their studies and showed that although erionite and mordenite have similar physico-chemical characteristics, erionite is much more toxic than mordenite, more than $6\mu\text{g}/\text{cm}^2$ of erionite bears mutagenic risk and that this risk seriously increases with ferrous iron. Erionite exists in various parts of the world, but the most serious disease risk is observed in some villages in Middle Anatolia in Turkey (Barış, 1987).

Main diseases related to minerals and mineral dusts: Asbestos: Asbestos, as a term, is used for naturally formed and resistant fibre-like silicates (of $<1\mu\text{m}$ diameter) displaying a flexible characteristic (Gibbons,

1998). Due to this characteristic, they have been processed for 4500 years and this caused wide exposure of humans to asbestos. Crysotile is the most wide asbestos type. Amosite and crocidolite follow chrysotile. Apart from these minerals, some other natural minerals may also have fibre-like structures (for instance some zeolites like erionite, wollastonite, palygorskite [attapulgitite], sepiolite), and many of them are used in the industry.

The original industrial use of asbestos fibres being used since Antiquity started in 1878 in a chrysotile mine in Quebec, and this was followed by crocidolite mining in 1910 and amosite mining in South Africa in 1916. The first recognition of asbestos-related diseases was after 1907 and data concerning the lung fibrosis, cancer, malignant mesothelioma defined among asbestos workers were reported between 1920 - 1950 (Leman et al., 1980). The common acknowledgement of the relationship between breathing asbestos and these diseases was only possible in 1950s and 1960s as a result of epidemiological researches of such cases among the asbestos workers (Checkoway et al., 1989). Asbestos-related diseases are asbestosis, pleural plaques, diffuse malignant mesothelioma, and especially for smokers increased lung cancer risk (Graighead et al., 1982; Kane, 1993; Shukla et al., 2003).

Many mine workers, millers, those working in places such as stone quarry and tunnel, agricultural workers are also exposed to mineral dusts other than asbestos. If these workers breathe these dusts for a sufficient intensity and period, pneumoconiosis and in some situations malignant neoplasms, and especially lung cancer may occur.

Silica minerals and amorphous silica: quartz (including chalcedony), cristobalite, moganite, tridymite, melanophlogite, coesite, and stishovite are naturally formed crystalline silica minerals and contain trace amounts of Al, Fe, Mn, Mg, Ca, and Na. Non-crystal silica (amorphous silica) contains natural glass and synthetic glass (such as smoked silica, fibre glass, mineral wool) existing in various volcanic rocks. Opal is naturally formed hydrated silica; in general, it is amorphous or approximately amorphous. Dusts made up of amorphous silica (except fibre glass) is not hazardous on human health. Diseases related to silica dusts are silicosis, silico-tuberculosis, and cancer (Ross et al. 1993).

Coal: It contains many different mineral groups like aluminium silicate, carbonates, sulphides and silica. Coal may lead to different health problems depending on its type, amount, and mineralogical characteristics (metal content, silica amount, and whether silica grains are covered with clay or not) (Finkelman et al., 2002): Problems caused by As, F, Se, and Hg as a result of use of coal as fuel, as it is observed especially in China; Balkan Endemic Nephropathia (BEN), a kidney disease, which develops as underground waters decompose toxic organic

compounds among pliocene old lignite and which is seen in some regions of Serbia, Romania, Bulgaria, Croatia, Bosnia, and Kosovo; and "Coal Worker Pneumoconiosis", known as "Black Lung Disease" among coal miners, and silicosis diseases as a result of coal dust inhalation. Stomach cancer observed among miners is much higher than the lung cancer (Enterline, 1964; Rooke et. al., 1979; Ross et. al., 1993; Kuempel et. al., 1995).

Geological environment: It is possible to discuss geological environment in two groups: 1) in relation to the formation of elements found naturally in the geological environment (for instance, in relation to deficiency or excess of elements); 2) in relation to elements generated as a result of natural disaster (for instance, volcanic explosions, earthquake, landslides, torrents).

Zone geology which has a direct effect on the local element content nourishes the soil, water and air in the environment and as a result this may cause positive or negative effects on humans, animals and plants in the same environment, depending on the intensity and diversity of the elements. Today, in developed countries, element distribution in food shows great diversity since the foods in question come from very different locations and are cultivated on totally different soils in terms of geochemistry. Because a very complex resource mechanism is generated by this way, element scarcity or toxicity is rarely observed. In addition, element imbalance in the soil is corrected before its effects augment (Underwood, 1979; Plat et. al., 1998; Bowman et. al., 2003).

More than 99 % of human body is composed of oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorous. There are many other elements in human body, as in rocks, however, these are in very low concentrations as trace elements (approximately 10 - 100 ppm or lower). While a very little deficiency in these elements may cause serious diseases, a very small amount may be toxic. Human, animal and plant health requires the acquirement of elements which are both very necessary like Ca, Cr, Cu, Fe, and Se and toxic like As, Hg, Pb. These types of elements exist in the atmosphere, lithosphere and hydrosphere in different concentrations and forms. All organisms need to intake the necessary elements in a specific tolerance range, in a sufficient amount and in a safe ratio. Concentration values of elements are represented with the curve defined as "dose-reaction curve" and this shows the ideal amounts of elements necessary for health as well as deficiency or toxicity levels. This curve shows difference form organism to organism for any element; but the basic principle of deficiency, ideal amount and toxicity remains the same. For instance, V which is very necessary for blue-green algae is very toxic for humans (Bowman, et. al., 2003).

The types of *natural disasters* affect also the dimensions of their effects on health. For instance, volcanoes and earthquakes make direct

effects on living species with emittance of ash and magma. Element input to the environment, triggered by landslides and mobility of elements may cause health problems in the short-term or in the long-term, depending on the amounts and intensity of the toxic elements. At the same time, direct risk may become indirect; for instance, volcanic ash directly affects lungs of the organisms; but it will probably insert hazardous elements to the food chain since it will also add new elements to the environment around the settlement area. Volcanism and associated hydrothermal activities lead metals and other potentially hazardous pollutants come up to the earth. Estimated yearly amount of such elements emitted is 9000 tons (Hinkley et. al., 1999). While direct effects of volcanic explosions include all sorts of effects from respiratory track problems to death, indirect effects show variety from landslides triggered by monsoons to soil pollution.

Volcanic explosions and volcanic ash causes very serious lung problems both in the short term and in the long term and it causes silicosis. Volcanic ash may contain cristobalite according to the composition of the volcanoes and to the type of the explosion. Long-term exposure to crystalline silica results in silicosis and malign lung disease (Baxter et. al., 1999; Wakefield, 2000). Earthquakes also have direct and indirect effects on human and animal health, and medical geology in particular is focused on the indirect effects. Many of such effects occur with landslides triggered by earthquakes and with earthquakes mobilizing the elements and other potential risk agents.

Anthropogenic factors: Humans damage the geological environment for various reasons (like soil, water and air pollution, mineral exploration and mining, radioactivity) and new health risks occur as a result of this. Many studies have shown that formation and distribution of diseases (such as cardiovascular pathology, malign neoplasms, trauma, and genetic anomalies) are related to pollution, urbanization, negative results in scientific and technological progress. Life conditions on earth are continuously damaged with negative environmental impacts (increase in CO₂ concentration; depletion of ozone layer, acid rains causing serious damage in various regions of the world; careless use of natural resources; effect of pesticides in soil, water, plants and animals and heavy metal radionuclide; destroying the forests; proliferation of erosion and desertification; decrease of bio-diversity). Effects of these become very serious concerning especially the genetic structure and physiological integrity of organisms (Komatina, 2004).

Passageways of elements to the organism

The most important source of trace elements in the body is the earth, especially the rocks. The air we breathe is also the source of some elements. Trace elements find ways in the body in a number of different manners and the trace element concentration is reshaped along this way. Rocks generally lose and sometimes get some of their chemical compounds while they are breaking up and transforming into soil. Agricultural chemicals and pollutants may be added while soil is losing some of its elements with decomposition. Crops select and draw from the soil the elements necessary for growing; animals, on the other hand, are affected by this selection through the plants they choose to get nourished. The latter processing and storage methods of our food also cause changes in their composition. Trace elements in our drinking water were also decomposed from rocks and soil. At the same time, they may be polluted or processed chemically before we drink.

Some techniques used in medical geology

Particularly in western European countries some important disease groups (cancers, diseases related to the central nerve system and cardiovascular diseases) have been mapped and diseases which can not easily be explained with genetic characteristics or differences depending on genetics or diet and which show great differences from region to region have been reported. The approach in mapping depends on this hypothesis: If environmental relationship in one region is positive, it is expected also to be positive in another geologically similar place. If not, the reason must be researched (Davies et. al., 2005).

Today, Geographical Information Systems (GIS), Remote Sensing satellites and other techniques are tools for scientists to see in a clear manner the relationship between issues like geographical relationship of diseases and occurrence of diseases, different vectors of disease agents, occurrence of diseases within populations (Aronoff, 1989). Data types that can especially be used by medical geology researchers among databases are those associated with geological sciences / with earth and with biomedical / health. Such a research may ensure that medical geology is a very distinctive and innovative branch of science. This approach may present new perspectives by recognizing the connection between environmental factors and data on human health, which may not have been recognized before and finally may transform into new practices and policies, it may lead to the discovery of new methods in the solution of problems.

Examples of environmental interaction with hazardous elements

In relation to some elements and minerals, there are many examples causing hazardous results in various regions in Turkey or belonging to regions bearing serious health risks (Atabey, 2005). Here some of them will be given in order to emphasize how crucial medical geology studies are especially in developing countries and for Turkey.

There is an important boron reserve and enterprise around Emet in Kütahya, and tuffs, tuffites, limestones and clays that make up the region's geology contain high rates of boron, arsenic, sulphur and strontium (Helvacı & Firman, 1977; Helvacı, 1986). Waters used had been brought to Emet district center for years from a geological structure rich of arsenic. Also in another village very close to the boron deposit, drinking water is still obtained from rocks rich of arsenic and skin defect (keratosis) on palm and on footing is observed among the village members (Barış, 2003c).

Waters escaping from an abandoned mine caused iron, copper, arsenic, mercury and sulphate pollution in surface and underground waters in Sızma, Konya. Heavy metal pollution may have caused the unusual animal deaths in the region and besides the problems of hearing and blindness in the villagers (Güzel et. al., 1998)

Eskişehir Beylikova Kızılcaören village, Uşak Esmé Güllü village, Isparta, and Tendürek volcano region water areas are regions with high ratios of fluorine in Turkey (Atabey, 2005). Tarnish teeth structure widely observed in Isparta is caused by fluorine in waters. However, the source of drinking water coming to the city has been changed since 1995 and it is brought from Eğridir Lake (Oruç, 1983).

According to the Ministry of Health, there is slight iodine deficiency in the western regions of Turkey and it increases on the way towards Middle Anatolia and Eastern Anatolia. Iodine deficiency affects thyroid glands and causes hypothyroid (goiter) disease. Its more advanced stage is cretinism and it shows indications like physical and mental retardation, deafness, mutism (Atabey, 2005).

Biological pollution generated by domestic and industrial wastes has been observed and nitrite, ammonium, and phosphate above the limits have been measured in chemical analysis carried out in Tuz Gölü (Atabey, 2005).

According to the analysis collected from Turkey in common, As, Cd, Co, Cr, Mn, Ni, Se, Tl, U and V in tertiary age coals were found to be higher than the world averages (Tuncali et.al., 2002).

In relation to problems caused by fibre-like minerals, mesothelioma which is observed in one person per million in the world is observed for thousand times more in some particular regions in Turkey (Tuzköy, Karain, Sarıhıdır). In some cases, non-mesothelioma tumors like lymphoma, liver cancer, bone sarcoma with pleural and peritoneal

mesothelioma (Bariş, 2002, 2003a). Researches show that erionite is the effective factor in cancer formation; but it is also stated that genetic tendency can also be effective (Bariş, 2003a).

Conclusions

Medical geology tries to understand the natural and the anthropogenic environment in which humans and animals exist and the relationship between such environment and the related health problems, and tries to solve the problems. Medical geology analyzes the whole earth and is interested in ecosystem health. Today, the relationship between the natural environment and health is recognized all over the world. Health problems in humans and animals due to regional geology are experienced in almost all continents and this varies from arsenic pollution in ground water to molybdenosis in cattle in Canada.

Medical geology studies investigate the presence or lack of trace elements. The compatibility between geo-chemical data and disease distribution shows that the two are very closely related. The frequency in the occurrence of certain diseases varies from region to region; it may not occur in some locations, while it is very wide in some other. From now on, the medical geologists may leap over attracting attention to the coincidence of such environmental factors and diseases on a regional basis. With the continuously developing calculation methods and capacity, combining highly developed statistical methods with GIS, advantages of different methods can be used and new methods in the solution of health problems can be found with new implementations and policies.

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