Historical aspects of medical geology

Article *in* Earth sciences history: journal of the History of the Earth Sciences Society · January 2020

DOI: 10.17704/1944-6187-39.1.172

Iskhak Farkhutdinov
Bashkir State University

Anvar Farkhutdinov
Bashkir State University

Irina Matveenko
Tomsk Polytechnic University

HISTORICAL ASPECTS OF MEDICAL GEOLOGY

ISKHAK FARKHUTDINOV[1]
iskhakgeo@gmail.com

LEYLA FARKHUTDINOVA[2]
farkhutdinova@gmail.com

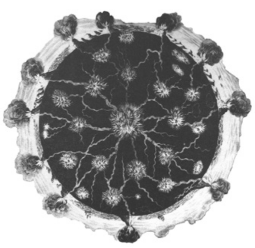
ANASTASIYA ZLOBINA[1,3]
anastasiyazl@mail.ru

ANVAR FARKHUTDINOV[1]
anvarfarh@mail.ru

IOSIF VOLFSON[4]
rosgeo@yandex.ru

IRINA MATVEENKO[3]
mia2046@yandexl.ru

1. Bashkir State University, Russia, 450076, Ufa, Zaki Validi Street, 32.
2. Bashkir State Medical University, Russia, 450076, Ufa, Lenin Street, 3.
3. Tomsk Polytechnic University, Russia, 634050, Tomsk, Lenin Street, 30.
4.Russian Geological Society (Rosgeo), Russia, 115191, Moscow, 2-d Roshchenskaya Street, 10



Earth Sciences History
Vol. 39, No. 1, 2020
pp. 172–183

ABSTRACT

The article examines the relationship between geology and human health from antiquity to today. The doctrine that man is a reflection of the universe was widespread in antiquity. In the Renaissance, the Swiss alchemist, physician and philosopher Paracelsus proclaimed the principle: “Everything is poison, everything is medicine; both depend on the dose”. Until the twentieth century, the role of microelements was identified in the development of only two diseases—hypoferric anemia and endemic goiter. The development of atomic-emission spectroscopy in the 1920s permitted the analysis of elements with exceedingly low concentrations in the environments being studied. Application of this analytical technique made it possible to measure the microelemental composition of soils, plants, animal tissues, and other matter, resulting in important scientific discoveries. Then information was collected on the vital necessity of microelements that previously had been considered as toxic to living organisms.

The explanation of different diseases caused by deficiency or excess of different elements was made—‘Bush disease’ among New Zealand cattle by the low content of cobalt in rocks, ataxia of lambs in some regions of Western Australia caused by copper deficiency, osteomalacia in a region of Norway caused by phosphorus deficiency in rocks, ‘white muscle disease’—cardiac muscle dystrophy caused by selenium deficiency, Keshan disease or endemic cardiomyopathy caused by selenium deficiency in soils and other.

With the increasing interest in medico-geological research there was a need to unite scientists from different countries. In 2004 the International Medical Geology Association (IMGA) was established. Its aim is to promote awareness concerning this issue among geoscientists, medical specialists, and the public at large. Medical geology is a relatively new scientific field that studies the influence of geological factors on health. The obtained results testify to the prospects of scientific research at the junction of medicine, geology, ecology, and the expediency of further in-depth study of the biological role of geological factors.

Keywords: geoecology, medical geology, trace element status, geochemistry, biogeochemistry
doi: 10.17704/1944-6187-39.1.172

An organism is inseparably connected with the environment, and one can separate it only in thought.
V. I. Vernadsky

1. INTRODUCTION: MAN IS A REFLECTION OF THE UNIVERSE

'Medical geology' is a relatively new scientific field that studies the impact of natural geological material (*e.g*. rocks, ores, minerals and water) and processes (*e.g*. weathering, erosion and volcanism), as well as anthropogenic phenomena (*e.g*. by-products of ore processing, alloys, and building materials), on the health of people, animals and plants. Medical geology research therefore takes place at the junction of medicine, geology, ecology and other disciplines.

The notion that the chemical composition of biological objects depends on the composition of their environment has long been recognized. For example, the idea of there being a relationship between animate and inanimate nature was widespread in antiquity as evidenced by the doctrine that man is a reflection of the universe (Tountas 2009). The Greek philosopher Democritus (*circa* 460−370 BC) asserted that there was nothing but cosmic elements in man (Korshunov 2014). Hippocrates (*circa* 460–370 BC), the founder of medicine, also developed ideas about the integrated nature of the human body and the environment (Låg 1990). For example, Hippocrates studied the impact of water quality on human health.

The earliest records of which we are aware concerning the influence of metals in rocks on human health, dates back to the third century BCE (Nriagu 1983). For instance, in Chinese medical texts, lead, silver, copper, antimony, gold, and iron were regarded as poisonous as they had a negative impact on the lungs of miners in the stone crushing industry (Nriagu 1983). In the Middle Ages, the Italian merchant Marco Polo (1254−1324) wrote a book about his journey to China where he described the horse illness that developed during his travels in the Chinese province of Kublai Khan (Latham 1958). Subsequently, it was found that the cause of the illness was a high selenium content in the soils (Moxon 1937).

In the Renaissance, the Swiss alchemist, physician and philosopher Paracelsus (1493−1541) argued that living organisms, like other bodies of nature, consist of the same substances, such as mercury, sulfur, and salts, and their excess or deficiency may cause diseases (Latham 1958). This was a period of intensive development in the mining industry, and Paracelsus, together with Georgius Agricola (1494−1555), a German physician and one of the founders of mineralogy, were the first to describe miners' lung cancer associated with lead, mercury and antimony poisoning (Selinus *et al*. 2005, p. 3). Paracelsus was a pioneer of chemical treatments, proclaiming the principle: "Everything is poison, everything is medicine; both depend on the dose" (Ando *et al.* 1998; Latham 1958).

In the second half of the nineteenth century, Russia became one of the centers of fundamental scientific development in the natural sciences due to the constellation of outstanding researchers active there at the time. For example, the creator of the physiological school, Ivan Mikhailovich Sechenov (1829–1905), was an advocate of the idea that organisms were inseparable from their environments, and he laid the foundation of bioelementology. In 1883, a famous book, *The Russian Chernozem*, was published by the founder of soil science Vasily Vasilyevich Dokuchaev (1846–1903). Dokuchaev insisted on the integrated study of animals, plants and the lithosphere. Karl Baer (1792–1876), one of the founders of the Russian Geographical Society, and an originator of embryology and comparative anatomy, demonstrated the effect of regional natural conditions on human health in his dissertation *On Endemic Diseases of Estonians*.[1] In 1916, Academician Vladimir Ivanovich Vernadsky (1863–1945) initiated a new scientific discipline—biogeochemistry—which investigates the relationship between the elemental composition of a living organism and its environment. He wrote: ". . . between . . . non-living and living natural

[1] The territory of Estonia was a part of the Russian Empire from 1721 to 1918.

matter existing in it there is a continuous physical and energy exchange substantially expressed in the movement of atoms . . ." (Vernadsky 1991, p. 42).

Vernadsky emphasized the special role of microelements in the vital processes and in 1928 he founded a laboratory to study trace element biogeochemistry at the USSR Academy of Science. In the 1940s, a new branch of biogeochemistry known as 'landscape science' was developed by Boris Borisovich Polynov (1877–1952), who proposed that the chemical composition of organisms depended on landscape characteristics, and therefore plants and animals of the same species, genus, and family, had different chemical compositions in different areas (Perel'man 1975).

The establishment of biogeochemistry was preceded by the work of the American chemist Frank Clark (1847–1931), who processed and synthesized more than 5000 analyses over 20 years. He stated that the portion of the Earth's crust that could be studied in order to determine its composition was 16 kilometers thick (Clark 1908). Clark's work was considered a scientific breakthrough, and as a consequence, the elemental abundances in the Earth's crust are expressed in 'clarks'. The determination of the average elemental content as a percentage of the Earth's crustal mass revealed that the most abundant elements were: oxygen (47%), silicon (29.5%), aluminum (8.05%), iron (4.65%), calcium (2.96%), sodium (2.5%), potassium (2.5%), and magnesium (1.87%). These are modern data, but they differ insignificantly from those of Clark. Cumulatively, all of these percentages total 99.03%. Thus, the abundance of all other elements combined is less than 1%.

In 1942 academician Vladimir Nikolaevich Sukachev (1880–1967) established a new science—biogeocenology—which deals with the interactions of living and non-living nature (Sukachev 1942)

2. THE TWENTIETH CENTURY: TOXIC ELEMENTS BECOME ESSENTIAL

Until the twentieth century, the role of microelements was identified in the development of only two diseases—hypoferric anemia and endemic goiter. For example, Pierre Blaud (1774–1858) reported on the efficacy of iron sulfate in anemia treatment (Blaud 1832). In 1849, French physicians A. Chatin and J. Prevost were the first to publish information on the relationship between endemic goiter and iodine deficiency in the environment (Solokhina 2005). In 1896, Eugen Baumann (1846–1896) proved that the function of thyroid glands was to concentrate iodine, and a deficiency in that function could lead to goiters (Solokhina 2005). These critical results were accomplished by the contribution of the new discipline of biogeochemistry to the field of microelemental human pathology.

The development of atomic-emission spectroscopy in the 1920s permitted the analysis of elements with exceedingly low concentrations in the environments being studied (Thomsen 2006). Application of this analytical technique made it possible to measure the microelemental composition of soils, plants, animal tissues, and other living and non-living matter, resulting in important scientific discoveries. For example, information was collected on the vital necessity of microelements that previously had been considered as toxic to living organisms.

The explanation of the etiology of 'Bush disease' among New Zealand cattle by Australian scientist Eric John Underwood (1905–1980) was one of the first such discoveries (Underwood 1937). This disease is characterized by anorexia, anemia, and progressive wasting and is known by various names in many countries: in the USSR – tabes, in the USA – Denmark disease, in Australia – enzootic idiocy, in Japan – kuvuza disease, to name a few. Underwood (1937) argued that the disease was caused by the low content of cobalt in rocks (Figure 1). That same year, Bennets and Chapman showed that ataxia of lambs in some regions of Western Australia was caused by copper deficiency (Bennetts and Chapman 1937). In 1938 Ferguson and colleagues described endemic molybdenosis of farm animals in a number of areas in England (Ferguson *et al.* 1938). Some years later, J. Vogt found that osteomalacia in a region of Norway was caused by phosphorus deficiency in rocks (Låg 1990). In the 1960s, the need for selenium for living organisms was discovered. The study of 'white muscle disease', the pathology of sheep and cattle manifested by cardiac muscle

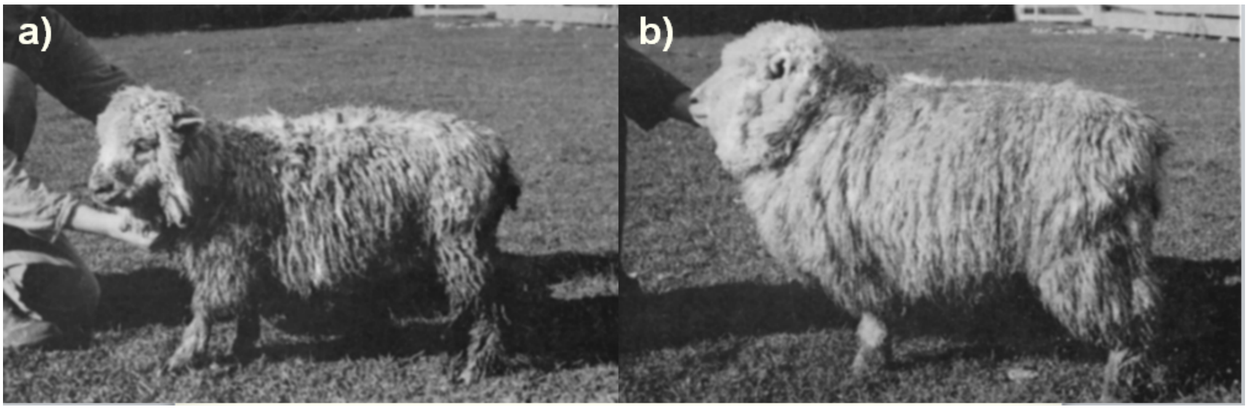


Figure 1. (a) Lamb that received a cobalt deficient diet, (b) lamb that received a cobalt adequate diet (Andrews 1965).

dystrophy and common in Great Britain, showed that the disease was caused by selenium deficiency (Anderson *et al.* 1979).

The issue of human dismicroelementosis is much more complicated than that of plants and animals, as the human organism is a final link in the geochemical chain. In addition to regional geochemistry, humans are influenced by a great number of factors that determine microelement status, including food quality and environmental pollution. The analysis of the roles of certain microelements, whether they are pathogenic or protective, is very difficult to accomplish because of their mutual interactions as well as their interactions with macroelements.

In 1937 it was shown that the occurrence of endemic osteoarthritis (Kashin-Beck disease) was connected with microelemental disbalance. This disease was first described by Mikhail Afanasievich Dokhturov (1800–1849) in 1839, but its fullest characteristic was given by the Russian doctors, Nikolai Ivanovich Kashin (1825–1872) in 1859 and Evgeniy Vladimirovich Beck (1865–1915) in 1906, after whom it was named (Eilbart 2006). The disease affected children between 4 and 14 in the period of skeleton development and led to rough bone deformity. It is common in Trans-Baikal, in the basin of the River Urov as well as in other areas of Western Siberia, in China, and Korea. The research results showed that Kashin-Beck disease was associated with calcium deficiency in bone tissue and it was seldom found among the population of the Urov region where people lived in a zone of calcareous rock outcrops (Koval'skij 1974). According to other authors, deficiency of selenium and iodine, as well as an excess of iron and copper, were significant in the development of this disease (Yunfeng *et al.* 2011; Derinience 2015) (Figure 2).

In the 1950s, owing to an outbreak of a disease in Japan in the upper reaches of the River Jintsu, it was shown that cadmium can have a great impact on human health (Chaney *et al.* 1998). The disease was characterized by excruciating pain in the bones, pathologic fractures, and renal failure, which typically was the cause of death. The disease was given its name, 'itay-itay', for its severe pain syndrome, which can be translated from Japanese as 'ouch boo-boo'. The disease was associated with cadmium intoxication, the source of which were mines (Chaney *et al.* 1998).

The serious Keshan disease affected mostly children and women of reproductive age, and typically occurred as heart failure. It was first described in the Chinese province of Keshan. In 1973 research results revealed that Keshan disease or endemic cardiomyopathy was caused by selenium deficiency in soils. Since 1974 selenium has been used to prevent Keshan disease (Yang *et al.* 1984; The Research Group, 1974).

In 1987 cardiomyopathy caused by selenium deficiency in the territory of Trans-Baikal was described. Simultaneously, the cancer-protective role of selenium was identified (Rosenfeld *et al.* 1964; Frankenberger *et al.* 1994).

Discovery of the dismicroelemental nature of human and animal diseases mentioned above made it possible to treat and preventively correct the microelement status. Underwood (1979) emphasized that the investigation of diseases caused by localized deficiencies, toxicities or disbalance of microelements, was the key scientific and economic contribution of microelementology.

Figure 2. Kashin-Beck disease patient (left) and woman of the same age (Tan 1989).

In the history of microelement research during the twentieth century, Gerhard Schrauzer distinguished two principle periods—from 1925 to 1956 and post-1957 (Schrauzer 1984). Within the first period, the biological roles played by microelements were studied by investigating local diseases. During the second period, the role of microelements in living organisms was studied using monocomponent diets. For example, K. Schwarz and Calvin Foltz conducted experiments modeling microelement-deficiency states in lab animals (Schwarz and Foltz 1957). As a result of those experiments, the list of vital microelements that had previously included seven metals—iron, iodine, copper, manganese, zinc, cobalt, and molybdenum—was supplemented by the following elements—selenium, chromium, vanadium, fluorine.

Viktor Vladislavovich Kovalski (1899–1984) was among the Russian scientists who contributed to the development of microelementology. He was a founder of geochemical ecology and was the first to perform biogeochemical zoning of the USSR territory (Kovalski 1974). He was the head of the Biogeochemical Laboratory of the USSR Academy of Sciences from 1960–1984. Because of the zoning, 'abnormal biogeochemical provinces' were identified. They were characterized by either the excess or lack of elements such as barium, boron, cobalt, calcium, copper, molybdenum, nickel, and so on. Different forms of microelement pathology in plants, animals and humans were described (Kovalski 1974). Great success was thereby achieved in agricultural sciences. For example, the correction of cobalt and copper concentrations in the diets of livestock animals in the areas that have deficiencies of these microelements in the soil, enabled their recovery.

Describing the regularities in microelement distribution of regions and subregions of the biosphere, Kovalski (1974) showed the active role played by plant roots that are capable of extracting chemical elements from poorly soluble compounds and, *vice versa*, preventing excessive intake of particular elements by means of organic acid secretion. Adaptive mechanisms provided stable chemical compositions for living organisms, whereas the disruption of regulatory functions in a population was often observed where there were significant deviations in microelements in the biosphere. It was necessary to take into account the adaptive ability where a qualitative assessment of chemical elements in a population was being undertaken. Evidence for adaptive ability included, first of all, plants that had been growing in a specific area for a long time. Those plants were directly connected with the soil of that area, and were therefore strongly influenced by the geochemical environment. Animals, in contrast, were indirectly connected with soil (*via* plants and other sources of food), which made them less dependent on the chemical conditions of the local biosphere. The different sensitivities of organisms to the natural chemical environmental factors resulted in a mosaic chemical structure of the biosphere. On the other hand, the geochemical heterogeneity of an environment was one of the key factors promoting species diversity. In the opinion of Alexey Ivanovich Tugarinov (1917–1977), specific changes to the microelement composition of the biosphere were crucial reasons for the evolution of life on Earth (Tugarinov 1973).

Based on collected information, microelements were classified into two groups: the essential microelements that were vital for the human organism, and the conditionally essential, the necessity for which had been documented in animals (Avtcyn *et al*. 1991). According to Alexander Pavlovich Avtcyn (1908–1993) and coauthors, the former group of microelements included iodine, zinc, copper, iron, chromium, selenium, manganese, cobalt, and molybdenum, and the latter group comprised arsenic, nickel, boron, bromine, fluorine, lithium, silicon, and vanadium (Avtcyn *et al*. 1991). In addition, Avtcyn *et al.* (1991) emphasized that the range of potentially essential microelements could be extended with advances in analytical techniques and scientific discoveries. At present more than thirty microelements, most of them metals, are considered necessary for living organisms (Gromova and Troshin 2019). Furthermore, Yuriy Ivanovich Moskalev (1920–1988) stated that an organism contained all chemical elements of the periodic table at variable concentrations. The biological roles of most elements, and their optimum concentrations, have not yet been studied (Moskalev 1989).

In the opinion of Porfiry Evdokimovich Kalmykov (1901–1971), water containing necessary microelements could be legitimately regarded as a nutrient (Avcyn *et al*. 1991; Shvarc 1996).

3. MEDICAL GEOLOGY: A NEW DISCIPLINE AT THE INTERSECTION OF SCIENCES

Beginning in the 1970s, mapping of disease distributions was undertaken not only in Western countries but also in other countries around the world (Tan *et al.* 1990). Those maps revealed considerable variation in indicators that were difficult to explain by either genetic or social factors. However, by that time, data on the relationships between various human pathologies and microelements in the environment had accumulated. As a result of lateral movement of the lithosphere, dense (ultrabasic) rocks of oceanic crust rich in metals are thrust up to the surface. Volcanism and hydrothermal processes also bring toxic and essential elements to the surface. The weathering and destruction of the minerals composing mafic rocks increase the concentration of many chemical elements in the environment. In the absence of tectonic activity, over millions of years, denser minerals and rocks would have been submerged under many kilometers of less dense material, and the availability of the former would have been greatly reduced (Kamaletdinov 1998, 2001; Farkhutdinov *et al.* 2017).

Regions where ‘specific’ diseases either occurred or were absent were often associated with mountainous areas with specific geochemistry (Volfson *et al.* 2010). For example, volcanic regions with basaltic lavas, were characterized by high concentrations of vanadium in the soils, which could result in high soil fertility and low rates of heart diseases (Ozol 1998). On the negative side, areas of active volcanism were associated with high rates of lung diseases such as asthma, silicosis and nonspecific pneumoconiosis, due to the inhalation of volcanic ash containing SiO_2 and thin-fiber asbestos minerals (Horton *et al.* 1964). Furthermore, subduction processes, such as those that occur in Chile, caused increased levels of arsenic in drinking water. Epidemiological studies revealed a set of health problems in the population of Chile, including arsenicosis, keratosis, hyperpigmentation, mental and physical retardation in children, and diseases of the cardiovascular and digestive systems (Smith *et al*. 1998).

Another example of an adverse impact that underlying geology can have on human health was the occurrence of fluorosis in some areas of India, China, Lithuania and Russia, which likely was due to the high concentration of fluorine in drinking water extracted from active deep fault zones (WHO 1984; Handa 1975; Ranasinghe *et al.* 2019).

One of the birthplaces of modern medical geology was Guizhou Province, China (Finkelman and Centeno 2020). There, in the 1980s, Professor Zheng Baoshan and his students recognized that a large number of people had clinical symptoms of arsenic poisoning, fluorine exposure, and other diseases caused by exposure to potentially toxic trace elements or due to deficiencies of essential elements. Their publications and collaboration with scientists who visited Guizhou Province resulted in increased attention by the scientific community to the health impacts of the natural environment (Zheng 1992). These and other research programs shed more light on the link between health and the environment (Skinner and Berger 2003; Komatina 2004; Dissanayake and Chandrajith 2009; Brevik and Burgess 2013; Censi *et al.* 2013; Duffin *et al.* 2013; Centeno *et al.* 2016; and Mori and Ibaraki 2017).

In 1996, an international Medical Geology Working Group (MGWG) was formed (Hasan *et al.* 2013). Its aim was to promote awareness concerning this issue among geoscientists, medical specialists, and the public at large. With the increasing interest in medico-geological research there was a need to unite scientists from different countries. In 2004 the International Medical Geology Association (IMGA) was established, the first elected chairman of which was Olle Selinus.

One of the products of the International Medical Geology Association was the book *Essentials of Medical Geology* (Selinus *et al.* 2005, 2006, 2010), which contained contributions from over sixty experts from around the world, about half of whom were geoscientists. Since its founding, the International Medical Geology Association has organized eight international conferences on medical geology, bringing together scientists from many countries.

More than 100 reports on the problems of medical geology were presented at the 33rd International Geological Congress (Oslo 2008) and this scientific direction was declared as one of the ten topics in the United Nations' International Year of Planet Earth.

Russian scientists were introduced to modern advances in the field of medical geology in May 2002, when American geochemist Robert Finkelman (born 1943), one of the leaders of the Medical Geology Working Group, gave a lecture at the V. I. Vernadsky State Geological Museum. In 2005 the Medical Geological Division of the Russian Geological Society was founded, headed by Iosif Faytelevich Volfson (born 1955). The seventh International Medical Geology Association conference was held in 2017 in Moscow. It was attended by 187 representatives of the geological and medical communities from thirty countries.

In recent years, interest in this issue has grown around the world. A number of studies have been published that contain analysis of geological factors and microelements of the environment and their influence on health. For example, the significance of tectonic dislocations on the development of cancer pathologies and other diseases has been demonstrated (Pronin *et al.* 2010). Also, the risk to human health has been considered from the point of view of the geochemical composition of not only groundwater (Drulyte 2003; Ranasinghe *et al.* 2018), but also soils (Abrahams 2002; Steinnes 2011; Oliver *et al.* 2018; Steffan *et al.* 2018), which inherit chemical elements from the underlying rocks or may be contaminated by human activities.

The mineral and geochemical composition of the human body is being actively investigated as a possible indicator for the elemental composition of the environment (Rikhvanov *et al.* 2013; Rikhvanov *et al.* 2017). In general, considerable data have been obtained that demonstrate chemical elements entering the human body from the environment have significant biological effects not only on individual organs but also the entire body (Komatina 2004; Lindh 2013; Centeno *et al.* 2016).

Over the past thirty years, the impact of natural radiation on health has been investigated (UNSCEAR 1993; UNSCEAR 2000; UNSCEAR 2009). Long-term human habitation in areas with geological formations containing uranium, thorium and their decay products (*e.g*. radon gas), often leads to the development of malignant neoplasms and other noncommunicable diseases. Radionuclide concentrations in vegetables were studied in areas with abandoned uranium mines. Ingestion of these vegetables was likely the main contributor to the radiation dose received by local populations (Carvalho *et al.* 2010). The latest research has shown that residents of areas with high background radiation levels and elevated radon gas levels suffer from various health problems, primarily related to the high risk of congenital defects of the fetus, the increase in leukaemia, and lung and nasopharynx cancer rates (Kochupillai *et al.* 1976; Bolviken 2001; Darby *et al.* 2005; Winde *et al.* 2017; Rodriguez-Martinez *et al.* 2018). Such problems have been observed in areas underlain by highly radioactive granites (for example, Guangdong Province in China, the Auvergne region in France, and Altai Krai and Novosibirsk Oblast in Russia) (Zlobina *et al.* 2019).

In the Republic of Bashkortostan, Russia, the mapping of diabetes, multiple sclerosis, and some forms of oncopathology have revealed the impacts of the regional geology on the occurrence of these diseases (Farkhutdinov *et al.* 2016). It has been found that populations living in the mountainous part of the Republic, or in territory underlain by limestones, experience a lower prevalence of diabetes.

A positive correlation between radon levels in homes and the incidence of leukemia in children in different countries has been demonstrated (Henshaw *et al.* 2002). In areas underlain by rocks with high concentrations of natural radionuclides there have occurred increased incidences of nasopharyngeal cancer (Bølviken 2001). Furthermore, studies conducted in the radon-prone region of Galicia in Spain have shown a link between residential radon levels and the risk of death from brain cancer (Ruano-Ravina *et al.* 2017). Radon and gamma radiation can be risk factors for other diseases in addition to cancer. With active inhalation of radon, there is a possibility of damaging the myelin sheath of nerve fibers of the brain and spinal cord, that can lead to multiple sclerosis. Recent studies in Ireland (Gilmore 2003), Sweden (Axelson 2001), and the United States (Eidbo 2004), have shown an increase in the incidence of multiple sclerosis associated with elevated radon concentrations in the air.

Together with medical indicators, geological factors begin to explain some socio-psychological phenomena. It has been clinically proven that lithium has suicide-prevention and other stabilizing effects on the human psyche (Knudsen *et al.* 2017). As a result, in areas with a lack of lithium in drinking water, there appear to be increased rates of suicide. The recognition that geological events, such as earthquakes and volcanic eruptions, as well as severe weather, impact not only individuals but also society as a whole, is gaining popularity. These natural disasters can cause social disasters such as epidemics, pandemics, wars, revolutions, and displacement of large numbers of people (Vikulin *et al.* 2015).

4. CONCLUSIONS

The geological environment and humans are two crucial links of the biogeochemical chain, where all constituents (for example, weathering rocks, surficial sediments, soils, plants, animals, and anthropogenic factors) determine the microelemental status and thereby determine environmental diversity. Studies of the geological environment are of fundamental significance to understanding the abundance of microelements, as it is rocks that initially contain and release by weathering the microelements that migrate into the environment. Investigation of the underlying geology provides a basis for determining the roles of other structural links in the biogeochemical chain.

Medical geology has come a long way since its inception—from philosophers of antiquity to modern interdisciplinary scientific teams. The results of medical-geological studies record the development of this interdisciplinary scientific field. Today, medical geology is experiencing a rebirth. Since the seventeenth century, science has become more specialized. The study of medical geology offers a means of reversing that trend. By taking a broad, multidisciplinary approach in the field of medical geology, there is the potential to solve many biological problems of general interest.

REFERENCES

Abrahams, P. W. 2002. Soils: Their implications to human health. *Science of the Total Environment* 291: 1–32.

Anderson, P. H., Berrett, S., and Patterson, D. S. P. 1979. The biological selenium status of livestock in Britain as indicated by sheep erythrocyte glutathione peroxidase activity. *The Veterinary Record* 104(11): 235–238.

Ando, M., Tadano, M., Asanuma, S., Matsushima, S., Wanatabe, T., Kondo, T., Sakuai, S., Ji, R., Liang, C., and Cao, S. 1998. Health effects of indoor fluoride pollution from coal burning in China. *Environment // Health Perspect* 106: 239–244.

Avtcyn, A. P., Zhavoronkov, A. A., Rish, M. A., and Strochkova. L. S. 1991. *Human Microelementosis*. Moscow: Mir. (In Russian).

Axelson, O., Landtblom, A.-M., and Flodin, U. 2001. Multiple sclerosis and ionizing radiation. *Neuroepidemiology* 20: 175–178.

Bølviken, B. 2001. Ecological analysis: Nasopharyngeal carcinoma and multiple sclerosis *versus* radioactive elements. *Natural Ionizing Radiation and Health. Proceedings from a Symposium held at the Norwegian Academy of Science and Letters, Oslo*. 126–134.

Brevik, E. C., and Burgess, L. C. (editors). 2013. *Soils and Human Health.* New York: CRC Press.

Carvalho, F. P., Oliveira, J. M., and Malta, M. 2010. Radiation safety of old uranium mining waste dumps in Portugal. *Advanced Materials Research* 107: 147–156.

Censi, P., Darrah, T. H., and Erel, Y. (editors). 2013. *Medical Geochemistry*. Dordrecht, Heidelberg, London, New York: Springer.

Centeno, J. A., Finkelman, R. B., and Selinus, O. 2016. Medical geology: Impacts of the natural environment on public health. *Geosciences* 6(1): 8, doi:10.3390/geosciences6010008.

Chaney, R. L., Ryan, J. A., Li, Y.-M., and Brown, S. I. 1998. Soil cadmium as a threat to human health. In: *Cadmium in Soils, Plants and the Food Chain*, edited by M. J. McLaughlin and B. R. Singh, 219–256. Dordrecht: Kluwer Academic.

Darby, S., Hill D., *et al*. 2005. Radon in homes and risk of lung cancer: Collaborative analysis of individual data from 13 European case-control studies. *British Medical Journa*l 330: 223–228.

Derin, M. T., Vijagopal, P., Venkatraman, B., Chaubey, R. C., and Gopinathan, A. 2012. Radionuclides and radiation indicate high background radiation area in Chavara-Neendakara placer deposits (Kerala, India). *PLoS ONE* 7(11).

Dermience, M. 2010. Kashin-Beck Disease: Evaluation of Mineral Intake in Young Tibetan Children from Endemic Areas*.* Bioengineering Master’s Thesis, University of Liège, Gembloux, Belgium.

Dissanayake, C. B., and Chandrajith, R. 2009. *Introduction to Medical Geology*. Dordrecht, Heidelberg, London, New York: Springer.

Drulyte, I. 2003. Drinking water: Safety issues in Lithuania. *Medical Geology Newsletter* 7: 20–21.

Duffin, C. J., Moody, R. T. J., and Gardner-Thorpe C. (editors). 2013. *A History of Geology and Medicine*. Special Publication 375. London: Geological Society.

Eidbo, W. B., and Prater, M. P. 2004. Linkage, multiple sclerosis and ionizing radiation. *Medical Veritas* 1: 272–276.

Eilbart, N. V. 2006 Study of Urovsk (Kashin-Bek) disease among children in Transbaikalia in the second half of the XIX – early XX centuries. *Questions of Modern Pediatrics* 5(5): 116–119. (In Russian).

Farkhutdinov, I. M., Farkhutdinova, L. M., and Sufijarov, R. S. 2016. Regional geological factors and diabetes mellitus. *Izvestija Tomskogo politehnicheskogo universiteta. Inzhiniring georesursov* 327 (3): 38–46. (In Russian).

Farkhutdinov, I. M., Ismagilov, R. A., Farkhutdinov, A. M., and Farkhutdinova, L. M. 2017. Murat Kamaletdinov and the struggle for acceptance of the thrust-nappe theory. *Earth Sciences History* 36(1): 101–115. doi: http://dx.doi.org/10.17704/1944-6178-36.1.101

Finkelman, R. B., and Centeno, J. A. 2020. Guizhou Province: The birthplace of modern medical geology. *Acta Geochemica*. 39(1): 155–159.

Frankenberger, W. T., and Benson, S. (eds.). 1994. *Selenium in the Environment.* New York: Marcel Dekker.

Gilmore, M., and Grennan, E. A. 2003. Pilot study of the relationship between multiple sclerosis and the physical environment in northwest Ireland. *Environmental Geochemistry and Health* 25: 157–163.

Gromova, O. A., and Torshin, I. Yu. 2019. *Micronutrients and Reproductive Health Manual*. Moscow: GEOTAR-Media. (In Russian).

Handa, B. K. 1975. Geochemistry and genesis of fluoride containing groundwater in India. *Ground Water* 13: 275–281.

Hasan, S., Finkelman, R. B., and Skinner, H. C. W. 2013. Geology and health: A brief history from the Pleistocene to today. In: *The Impact of the Geological Sciences on Society*, edited by Marion E. Bickford, 155–164. Boulder: Geological Society of America Special Paper 501.

Henshaw, D. L., and Allen, J. E. 2002. Is indoor radon linked to leukaemia in children and adults? – A review of the evidence. *Natural Ionizing Radiation and Health. Proceedings from a Symposium held at the Norwegian Academy of Science and Letters, Oslo*. Otta: AIT Enger A/S.

Horton R. J. M., and McCaldin R. O. 1964. Observations on air pollution aspects of Irazu volcano, Costa Rica. *Public Health Reports* 79: 925–929.

Ibaraki, M., and Mori, H. (editors). 2017. *Progress in Medical Geology*. Newcastle upon Tyne: Cambridge Scholars Publishing.

Kamaletdinov, M. A. 1998. The new geology (thrust-nappe theory). Geologija. *Izvestija Otdelenija nauk o Zemle i prirodnyh resursov Akademii nauk Respubliki Bashkortostan*. 3:10–23. (In Russian).

Kamaletdinov, M. A. 2001. The modern thrust-nappe theory. *Geologichesky Sbornik* 2: 29–37. (In Russian).

Knudsen, N., Schullehner, J., Hansen, B., Jørgensen, L., Kristiansen, S., Voutchkova, D., Gerds, T., Andersen, P., Bihrmann, K., Grønbæk, M, and Kessing, L. 2017. Lithium in drinking water and incidence of suicide: A nationwide individual-level cohort study with 22 years of follow-up. *International Journal of Environmental Research and Public Health* 14(6): 627.

Kochupillai, N., Verma, I. C., Grewal, M. S., and Ramalingaswami, V. 1976. Down's syndrome and related abnormalities in an area of high background radiation in coastal Kerala. *Nature* 262: 60–61.

Komatina M. 2004. *Medical Geology: Effects of Geological Environments on Human Health.* Amsterdam: Elsevier.

Korshunov, P. A. 2014. Epistemological foundations of the philosophy of Democritus: Between the concept and representation. *Omsk scientific Bulletin* 3(120): 70–72. (In Russian).

Kovalski, V. V. 1974. *Geochemical Ecology Essays.* Moscow: Nauka. (In Russian).

Låg, J. 1990. General survey of geomedicine. In: *Geomedicine*, edited by J. Låg, 1–24. Boca Raton, FL: CRC Press.

Latham, R. 1958. *The Travels of Marco Polo*. London: Penguin Books.

Lindh, U. 2013. Biological functions of the elements. In: *Essentials of Medical Geology*, edited by Olle Selinus, 129–177. Berlin: Springer.

Moskalev, Yu. I. 1989. *Radiobiology of Incorporated Radionuclides*. Moscow: Energoatomizdat. (In Russian).

Moxon, A. L. 1937. Akali disease, or selenium poisoning. *South Dakota Agricultural Experimental Station, Brookings*, Bulletin 331.

Nriagu, J. O. 1983. *Lead Exposure and Lead Poisoning in Antiquity*. New York: John Wiley & Sons, 309–424.

Oliver, M. A., and Gregory, P. J. 2015. Soil, food security and human health: A review. *European Journal of Soil Science* 66: 257–276.

Ozol, A. A. 1998. Human geoecology as a promising scientific direction in natural science. *Problemy geo- i sociojekologii respubliki Tatarstan,* 3–51. Vyp. I. Kazan': Jekocentr. (In Russian).

Perel'man, A. I. 1975. *Geochemistry of the Landscape*. Moscow: Vysshaja shkola. (In Russian).

Pronin, A. P. Volfson, I. F., Oderova, A. V. 2010. Fluid activity of the earth and habitat, biogeochemical provinces, geopathogenic zones, human geoecology. In: *Medical Geology: Status and Prospects*. Moscow: Rosgeo (In Russian).

Ranasinghe, N., Kruger, E., and Tennant, M. 2019. Spatial distribution of groundwater fluoride levels and population at risk for dental caries and dental fluorosis in Sri Lanka. *International Dental Journal*. doi: 10.1111/idj.12476.

Rihvanov, L. P., Baranovskaja, N. V., and Sudyko, A. F. 2013. Chemical elements in the human body as the basis for implementing the ideas of medical geology. *Gornyj zhurnal* 3: 37–42. (In Russian).

Rikhvanov, L. P., Deriglazova, M. A., and Baranovskaya, N. V. 2017. Mineral and geochemical composition of human body ash residue of Norilsk residents as a possible indicator of elemental composition of the environment. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering* 328(9): 67–81. (In Russian).

Rodriguez-Martinez A., Torres-Durin M., Barros-Dios J. M., and Ruano-Ravina A. 2018. Residential radon and small cell lung cancer. A systematic review. *Cancer Letters* 426: 57–62.

Rosenfeld, I., and Beath, O. A. 1964. *Selenium: Geobotany, Biochemistry, Toxicity, and Nutrition*. New York: Academic Press.

Ruano-Ravina, A., Aragonés, N., Kelsey, K. T., Pérez-Ríos, M., Piñeiro-Lamas, M., López-Abente, G., and Barros-Dios, J. M. 2017. Residential radon exposure and brain cancer: An ecological study in a radon prone area (Galicia, Spain). *Scientific Reports* 7(3595): 2–7.

Schrauzer, G. N. 1984. The discovery of the essential trace elements: An outline of the history of biological trace element research. In: *Biochemistry of the Essential Ultratrace Elements*, 17–31. Boston, MA: Springer.

Schwarz, K., and Foltz, C. M. 1957. Selenium as an integral part of factor 3 against dietary necrotic liver degeneration. *Journal of the American Chemical Society* 79(12): 3292–3293.

Selinus, O., Alloway, B., Centeno, J. A., Finkelman, R. B., Fuge, R., Lindh, U., and Smedley P., editors. 2005. *Essentials of Medical Geology*. Amsterdam: Elsevier.

Selinus, O., Alloway, B., Centeno, J. A, Finkelman, R. B., Fuge, R., Lindh, U., and Smedley, P. (editors). 2006. *Essentials of Medical Geology*. Chinese Edition. Translated by Zheng Baoshan and Wang BinBin. Beijing: Science Press.

Selinus, O., Centeno, J. A., and Finkelman, R. B. (editors.). 2010. *Medical Geology – A Regional Synthesis*. Dordrecht, Heidelberg, London, New York: Springer.

Shvarc, A. A. 1996. *Ecological Hydrogeology*. SPb.: Izd-vo SPbGU.

Skinner, H. C., and Berger, A. R. (editors). 2003. *Geology and Health: Closing the Gap*. New York: Oxford University Press.

Smith, A. H., Goycolea, M., Haque, R., and Biggs, M. L. 1998. Marked increase in bladder and lung cancer mortality in a region of northern Chile due to arsenic in drinking water. *American Journal of Epidemiol*ogy 147: 660–669.

Solokhina, M. E. 2005. History and current state of prevention of iodine deficiency diseases. Abstract of the dissertation for the candidate of medical sciences. Moscow. 28 p. (In Russian).

Steffan, J. J., Brevik, E. C., Burgess, L. C., and Cerdà, A. 2018. The effect of soil on human health: An overview. *European Journal of Soil Science* 69: 159–171.

Steinnes, E. 2011. Soils and human health. In: *Sustaining Soil Productivity in Response to Global Climate Change: Science, Policy, and Ethics*, edited by T. Sauer, J. M. Norman and M. V. K. Sivakumar, 79–86. Chichester: John Wiley & Sons, Inc.

Sukachev, V. N. 1942. The idea of development in phytocenology. *Soviet Botany* 1–3: 5–17.

Tan, J. (editor). 1989. *The Atlas of Endemic Diseases and Their Environments in the People's Republic of China*. Beijing: Science Press.

Tan, J., Peterson, P. J., Ribang, L., and Wang, W. (editors). 1990. *Environmental Life Elements and Health*. Beijing: Science Press.

The Research Group of Keshan Disease of Chinese Academy of Medical Science. 1974. National Symposium of the Etiology of Keshan Disease. 173 p.

Thomsen, V., 2006. A timeline of atomic spectroscopy. *Spectroscopy*, 21(10): 32–42.

Tountas, Y. 2009. The historical origins of the basic concepts of health promotion and education: The role of ancient Greek philosophy and medicine. *Health Promotion International* 24(2): 185–192.

Tugarinov, A. I. 1973. *General Geochemistry.* Moscow: Atomizdat. (In Russian).

Underwood, E. J. 1979. Trace elements and health: An overview. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences* 288: 5–14.

UNSCEAR. 1993. Sources and effects of ionizing radiation. In: *Report to the General Assembly of the United Nations with Scientific Annexes, United Nations Sales Publication, E.94.IX.2*. New York: United Nations.

UNSCEAR. 2000. United Nations Scientific Committee on the effects of atomic radiation. In: *UNSCEAR 2000 Report to General Assembly, with Scientific Annexes, Sources and Effects of Ionizing Radiation.* New York: United Nations.

UNSCEAR. 2009. United Nations Scientific Committee on the effects of atomic radiation. UNSCEAR 2009 Report: Annex E: Source-to-effects Assessment for Radon in Homes and Workplaces. New York: United Nations.

Vernadsky, V. I. 1991. *Scientific Thought as a Planetary Phenomenon*. Edited by A. L. Yanshin. Moscow: Nauka. (In Russian).

Vikulin, A. V., Volfson, I. F., Grachev, L. A., and Dolgaya, A. A. 2015. Geology, medicine and society. *Vestnik KRAUNTs, Earth Sciences* 1(25): 41–55. (In Russian).

Volfson, I. F., Paul, W., and Pechenkin, I. G. 2010. Geochemical anomalies: Sickness and health. In: *Man and the Geosphere (Earth Sciences in the 21st Century)*, edited by I. V. Florinsky, 69–113. New York: Nova Science Publishers.

WHO Guidelines for Drinking Water Quality. 1984. Geneva: World Health Organization.

Winde F., Erasmus, E. B., and Geipel, G. 2017. Uranium contaminated drinking water linked to leukaemia: Revisiting a case study from South Africa taking alternative exposure pathways into account. *Science of the Total Environment* 574: 400–421.

Yang, G., Chen, J., Wen, Z., Ge, K., Zhu, L., Chen, X., and Chen, X. 1984. The role of selenium in Keshan disease. In: *Advances in Nutritional Research*, edited by Harold H. Draper, 203–231. Boston, MA: Springer.

Yao, Y., Pei, F., and Kang, P. 2011. Selenium, iodine, and the relation with Kashin-Beck disease. *Nutrition* 27(11–12): 1095–1100.

Zheng B. 1992. *Research on Endemic Fluorosis and Industrial Fluorine Pollution.* Beijing: Chinese Environmental Science Press.

Zlobina, A. N., Rikhvanov, L. P., Baranovskaya, N. V., Farkhutdinov, I. M., and Wang, N. 2019. Radioecological hazard for the population living in the regions with high radioactive granites. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering* 330(3): 111–125. (In Russian).