apples. The first symptoms are manifested on the youngest organs, the plants take on a bushy appearance, they lag significantly in growth, and signs of chlorosis and necrosis are soon observed on the leaves. Calcium deficiency has recently occurred with increasing frequency on apple fruits.

The presence of a greater amount of calcium in soil can affect the accessibility of certain soil microelements (B, Mn, Fe, Cu, and Zn), with *chlorosis* in plants as a possible consequence. Some fruits (peach, bird cherry, etc.) and certain decorative plants are especially sensitive to chlorosis caused by a surplus of calcium.

*Magnesium.* This earth - alkaline metal is very widespread in nature. It is very similar to calcium in chemical properties. However, its role in plant metabolism is significantly different. In greater concentrations, magnesium is much more toxic than other essential macroelements. Symptoms of deficiency of this element were first noticed in regions where potassium fertilizers were used in increased amounts for a number of years. They were subsequently observed on fields irrigated with water containing large quantities of sodium. An inverse correlation also exists between manganese content and magnesium content.

Both deficiencies and surpluses of magnesium can cause morphological, anatomical, and physiologo - biochemical changes in plants. Surpluses of this element occur rarely in nature, primarily on soils formed from dolomites and serpentines.

**Essential Microelements**. It has long been observed that iron, zinc, manganese, copper, boron, molybdenum, and cobalt are needed in addition to the described essential macroelements for normal growth and development of plants. Discovery of the importance of these microelements in the life of plants made it possible to explain a whole series of phenomena leading to abnormal anatomical and morphological changes in plants. Thanks to the further development of science, many physiologo - biochemical processes have been discovered in which microelements play a significant part. Moreover, it is increasingly possible to detect in nature latent and acute signs of deficiency of essential microelements.

*Iron.* Iron is among the elements needed by plants. Its polyvalence and ability to form chelate comples are two significant characteristics that account for the important activity of iron in many physiologo - biochemical processes of plants. Symptoms of iron deficiency are today widely disseminated, especially in fruits and grapevine. Registered in different regions of Yugoslavia, *Fe - chlorosis* leads to significant decrease of the yield.

Iron surpluses occur rarely in nature, and for this reason there are very few data pertaining to them in the literature.

*Copper.* Copper belongs to the group of elements whose role in plant metabolism is predominantly catalytic. Owing to the fact that it enters the composition of enzymes, copper indirectly or directly affects many processes important for plant life. Copper deficiency in plants is an occurrence more widespread than is often supposed. It has been observed in many countries throughout the world, and many soils in Western Europe are deficient in copper. Dangerous diseases of livestock such as *chronic diarrhea, enzootic ataxia,* etc. occur on pastures whose vegetation does not contain enough copper. Copper surpluses also have an adverse effect, not only on plants, but through them on the state of health of man and animals as well.

*Manganese.* This is an important regulator of redox processes in plants. Manganese activates a number of enzymes, including many that regulate very important processes. On the basis of its role in plant metabolism, manganese is counted as one of the heavy metals most significant in the life of plants. Its deficiency occurs predominantly on lime and alkaline soils. Inadequate provisioning of plants with this element causes characteristic morphological, anatomical, and cytological changes. Especially sensitive to diseases caused by manganese deficiency (*dry spot, chlorosis*) are oats, potato, fodder and sugar beet, red beet, bird cherry, citrus fruits, and apples.

Symptoms of manganese surplus in plants under natural conditions are more widespread than might be imagined. On soils with high manganese content, low pH, and a high reducing potential, plants can accumulate manganese to such an extent that it becomes toxic for them.

*Zinc.* Zinc in small quantities is needed by higher and lower plants, as well as by man and animals. Due to the multiple role of zinc in plant life, its deficiency causes considerable changes, both in metabolism and in anatomical structure. Occurrence of zinc deficiency in perennial plants is very common throughout the world, and in Yugoslavia is especially pronounced on alluvial soils, chernozem, and loess. Large concentrations of zinc (as in the case of other metals) act toxically on plants, and the resistance of individual plant species to surpluses of this metal is extremely variable.

*Boron.* Boron is needed by higher plants, and its deficiency or surplus - especially in dicots - causes significant physiological and morphological changes. Toxic action of boron in crop plants can be expected when the content of this element (dissolved in boiling water) in soil exceeds 5 ppm.

*Molybdenum.* The significance of molybdenum and need for it in plant metabolism have been established in many experiments. Deficiency of this element usually occurs on acidic soils. Symptoms of molybdenum deficiency have been most thoroughly studied in cauliflower, since this plant is especially sensitive to it. The resistance of individual plant species to molybdenum surplus varies. High content of this element in fodder can have an unfavorable effect on the state of health of animals, causing molybdenosis in them.

*Cobalt.* Cobalt is a regular ingredient of plant cells, but its role in vital processes is not well enough known. It enters the composition of vitamin $B_{12}$, and for this reason its content in plants is of great significance for human and animal health. In normal circumstances, cobalt never accumulates in plant cells in great enough measure to be toxic for animals and people.

**Microelements That Can Ert Physiological Action.** In addition to the seven essential microelements, plants also contain 14 other elements whose individual concentration in dry matter usually does not exceed 2 ppm, but which can affect synthesis of organic substances in a favorable way and take part in physiologo - biochemical processes. Special attention has been devoted more recently to study of the harmful (toxic) action of certain microelements. Of the group of toxic elements, the influence of nickel, fluorine, and lithium on vital processes of plants has been studied in greatest detail.

*Nickel.* Nickel is chemically and physiologically similar to cobalt. Its role in physiological processes of plants is multiple. On the practical side, the influence of this metal on the yield of cultivated plants is very significant. Certain authors unjustifiably ignore the undoubted favorable action of nickel on plant growth and development, placing it in the group of elements with predominantly harmful action. This is especially wrong because many essential heavy metals - copper or cobalt for instance - at high concentrations are no less toxic than nickel.

*Fluorine.* At certain concentrations, fluorine can significantly affect the overall metabolism of plants and thereby influence their growth and development. Like many other elements, fluorine in higher concentrations can have a very unfavorable effect (causing *necrosis* and other conditions). Negative influence in some cases is manifested at low concentrations, due to the cumulative action of fluorides.

*Lithium.* Lithium affects certain physiologo - biochemical processes of plants and in some cases can even stimulate their growth and development. Higher concentrations of this element can cause morphological changes in both vegetative and reproductive organs of plants. Citrus plants are especially sensitive to higher concentrations of lithium.

**Useful Elements.** These are elements that are not needed by plants, but which in certain concentrations can stimulate their growth and development. They include above all sodium, silicon, and chlorine.

*Sodium.* The presence of this element can favorably affect growth and development of sugar beet, alfalfa, and other plants, and it can even be essential for certain halophytes. Sodium deficiency occurs very rarely in nature. Unfavorable action of its surplus occurs more often, especially on salinized soils, where it can be toxic.

*Silicon.* Favorable action of silicon on plant growth and development has been demonstrated in many studies carried out to date. Since it is in nature the second most widespread metal in the Earth's crust, symptoms of silicon deficiency have been recorded in few places, primarily fields of rice, oats, onions, and beans. Toxic action of this element has not yet been recorded.

*Chlorine.* The role of this element in vital processes of plants is still not well enough known, but it is a fact that chlorine deficiency causes various morphological and physiological changes in plants. On the other hand, it erts toxic action if its concentration in dry matter attains 0.5 to 1.8%.

## *Role of Elements in Nutrition of Animals and Humans*

Continuous exchange of substances with the surrounding environment is a common characteristic of all living organisms regardless of the degree of their development. This exchange is especially characteristic or quantitatively more pronounced in higher forms of living organisms, a category that includes man and animals, particularly ones raised for production of milk, meat, wool, etc. In the healthy organism of animals raised for production of something, milk for example, anabolic processes prevail over catabolic ones and primarily depend on the chemical composition of plants. The chemical composition of animals and man cannot be studied apart from that of soil, water, plants, food, and the surrounding medium, i.e., the atmosphere (Fig. 2.40.). This means that nutrition of animals and man, like all responses of the living organism to natural and artificial factors of the environment, must be studied within the framework of a system that includes *rocks, water, soil, air, plants, animals, and man,* with whom the circle is closed. Studying overall relations of the system's components enables us to model many vital processes, which should ensure a long and healthy life.

Systematic study of the chemical composition of upper layers of the Earth's crust - as well as that of plants, animals, man, sea water, and the atmosphere - has shown that the former erts definite influence on the latter. Moreover, certain regularity exists in the distribution of chemical elements between the Earth's crust and the biosphere. It is logical that the chemical composition of all living organisms is directly correlated with that of food and water, i.e., with that of the environment in which they live. Of 89 natural chemical elements in the Mendeleyev periodic system, about 45 have been identified in the living organisms of animals, plants, and humans, and a biochemical role has been established for 27 chemical elements. These are the so - called *bioelements.*

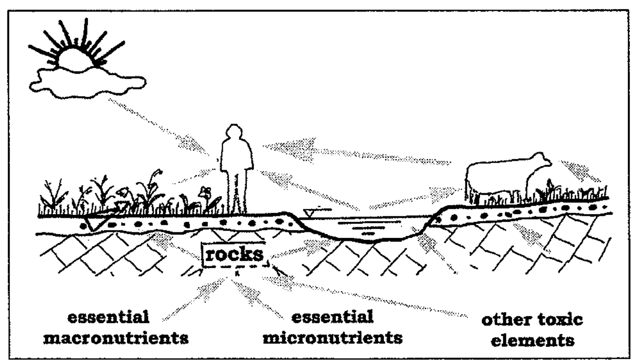


Fig. 2.40. Transport of natural trace elements within the *system rocks - soil - plants - animals - humans.*

In growth and development of animals and man, macro - and microelements are needed for mineralization of growing tissues, formation of the fetus in pregnant females, egg formation in egg - laying hens, wool growth in sheep, hair growth in different domestic animals (cattle, goats, and pigs), renewal of tissues, etc. It is therefore very important that they be systematically introduced into the organism for maintenance of life, health, and productivity.

Medical science started to take an interest in microelements and their role in pathological processes only since the beginning of the 20th Century (L. R. Nozdrjuhina, 1977), even though Vernadskii much earlier than that called attention to their enormous role in the biochemical processes of organisms. Studying geochemical processes in the Earth's crust, Vernadskii discovered the part played by organisms in these processes and stressed the interconnection between them and the evolution of living creatures.

On the whole, macro - and microelements perform numerous and very diverse functions in all organisms. Their biochemical characteristics and thereby their biological and physical roles depend on the position they occupy in the periodic system of Mendeleyev (Fig. 2.38.). With the exception of molybdenum, tin, and iodine, most of the elements of interest to us have a low ordinal number (below 34) and belong to the first to fourth periods of the system. On the basis of the periodic system and periodic law, it is possible to predict with high probability which chemical elements can have an essential role in metabolic processes. For example, the position of aluminum and silicon in the periodic system and their properties suggest that they could be involved in the building of complex biologically active compounds, whereas lithium and beryllium could be expected to play a structural role in enzymes. It is also noticeable that with the transition from light to heavy metals of the same sub - group - for example, the *zinc - cadmium - mercury* sub - group - the toxicity of an element increases at the same time as its quantity in the organism decreases (Fig. 2.41.). In all of this, it should be kept in mind that much also depends on the nature and kind of living organism (plant, animal, or human) and its physiological state.

Within the organism, macro - and microelements are unevenly distributed among organs and tissues. However, a constant reversible dynamic equilibrium exists between them in the healthy organism. The majority of microbioelements are found in greatest concentration in the liver, and the liver is for this reason considered to be the functional depot of these elements in the organism (D. Kolarski, 1995). Due to their great mass, bone and muscle tissues are storage places for elements such as calcium and phosphorus. Also, large amounts of some other elements are present in certain tissues: iodine in the thyroid gland, manganese and chromium in the hypophysis, zinc in the pancreas, etc.

Microbioelements can ert specific and non - specific influence on metabolic processes. Examples of specific influence are the connection between zinc metabolism in pancreatic tissue and biosynthesis of insulin; influence of iodine on the function of the thyroid gland; etc. On the other hand, copper, cobalt, fluorine, and some other microelements ert non - specific influence on the function of this gland.

Different mineral ingredients act in combination with vitamins, enzymes, and proteins, jointly stimulating and thereby regulating the course of complex biochemical reactions. Hence it follows that a deficit of any mineral or microelement involved will cause the given set of functions to be disturbed. Instead of unimpaired occurrence of the described processes, a serious breakdown arises in the work of certain organs or the organism as a whole (Fig. 2.38.). A state of disease sets in due to the deficiency of some element, whereas a surplus of it - if not toxic - can still be harmful.

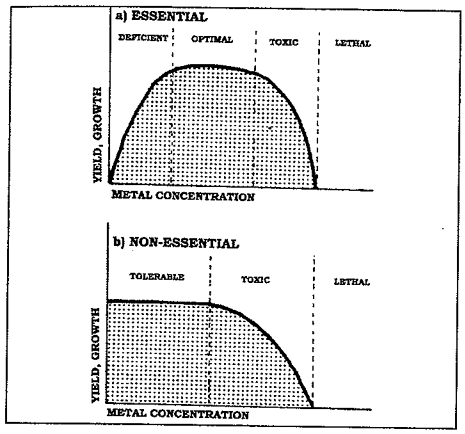


Fig. 2.41. Deficiency and surplus consumption of essential and non - essential elements in traces (C.B. Dissanayake, R. Chandrajith, 1999.).

As we have seen, the basic functions of macro - and microelements are very diverse and numerous, depending on the nature of the element, the kind of compound, and its structure. The biochemical and biological functions of macrobioelements (Ca, Mg, Na, Cl, K, P, and S), microbioelements (Mn, Fe, Co, Cu, Zn, Se, Mo, I, and F), and other microelements (Si, V, Cr, Ni, As, Sr, Cd, Sn, Hg, Pb and Ta) are discussed below, together with the effects of their deficiencies and surpluses. For this discussion, we rely on the book of D. M. Kolarski "**Fundamentals of Nutrition of Domestic Animals**" (1995) and other works.

**Macrobioelements.** *Calcium.* Calcium has an important role in the biosphere and represents a typomorphic element for many natural environments. A natural environment is considered favorable if it is rich in calcium. A calcium deficit in some environment reduces fertility of the soil, renders it acidic, and affects living organisms. For this reason, combating calcium deficiency represents a very important means of increasing the biological productivity of soil and improving public health.

Calcium is the most abundant metal in the human organism, making up about 1.5% of the weight of an adult person. The bulk of calcium is found in the skeleton. Mineralization of the organic matrix of bone tissue is one of the key roles of this macroelement, but it is also unusually important for normal functioning of nerves, muscles, and the heart. A portion of calcium is found in body fluids in the form of calcium carbonate. Ionic calcium has many functions: it is needed for maintenance of blood vessel tonus, contraction of myocardial muscles, and transmission of nervous impulses. Moreover, calcium takes part in virtually all phases of blood coagulation and is absolutely necessary for secretion of gastric juice, activation of some enzymatic reactions, and secretion of certain hormones. It promotes absorption of iron in the intestines, alleviates insomnia, generally stabilizes nervous and psychic functions, and is important during pregnancy and the period of nursing...

A deficiency or surplus of calcium in the diet of humans and animals is manifested in characteristic biochemical changes and clinical symptoms: rickets, curvature of the spine and ribs, loss of appetite, lameness, osteomalacia (softening of the bones due to their demineralization), osteoporosis, etc. In the case of a more prolonged deficit of calcium, "leaching" of this element from the bones causes increased absorption of lead from polluted environments and its incorporation into bones and teeth. If calcium is present in excess, its absorption from the lumen of the small intestine increases, which causes increase of calcium concentration in the blood or *hypercalcemia*. The recommended daily dose of calcium in humans is 600 - 1,200 mg/l, depending on a person's age and physiological state.

*Magnesium.* Magnesium is an element well represented in the Earth's crust. Its content in soil depends in large measure on the parent rock and its mineral and chemical composition. Magnesium cations are the fourth best represented cations in the organism of man. Together with calcium and phosphorus, it forms the foundation of bone tissue, and 60 - 70% of all magnesium in the human organism enters the composition of bones. It is a biologically essential element not only for humans, but for animals and plants as well. Magnesium plays an exceptionally important role in human metabolism, taking part in the activation of about 300 enzymes. It is vitally important for unimpaired functioning of nerves and muscles. Magnesium contributes to health of the cardiovascular system and serves to prevent cardiac stress. It slows the aging process, prevents clogging of the blood vessels, and helps to lower, i.e., normalize, the level of cholesterol in the blood. Together with calcium, magnesium acts as a natural calming agent, assists in combating stress, and helps to overcome periods of depression. Intercellular deficiency of magnesium is a significant etiological factor in the occurrence of hypertension. Deficiency of this important element in human nutrition is being increasingly studied because it can be linked with the pathogenesis of cancer or heart disease and stroke in regions with soft water.

In animals, magnesium deficiency in the food they consume is manifested in very diverse symptoms. In calves, these symptoms include decrease of magnesium concentration in the blood, mobilization and consumption of magnesium from the bones, and typical tetany and death. In egg - laying hens, magnesium deficiency results in hypomagnesaemia and reduction of lying, while in adult animals out to pasture it gives rise to hypomagnesaemia known as *grass tetany*.

*Sodium and chlorine.* The need for salt or sodium chloride has been manifested since man and animals started to feed on plants, which are for the most part poor in sodium and chlorine. Salt loss is especially pronounced in animals and humans in warm regions, where significant amounts are lost through sweating.

These two elements are linked in metabolic processes. Salt deficiency in consumed food is manifested in loss of appetite, slowed growth, and decrease in the amount of milk in mammals. If animals do not take in salt over longer periods of time, their body weight decreases significantly and they experience hair loss, exhaustion, etc. On the other hand, symptoms of strong poisoning can be manifested in animals if they consume large quantities of salt.

In living tissue of humans, sodium is found almost exclusively in the form of the $Na^{+}$ ion. Reduction of intake of this element into the organism is recommended for all persons, especially individuals suffering from hypertension. Consumption of large amounts of sodium directly affects (lowers) calcium content in the organism and influences the occurrence of osteoporosis and kidney disease.

*Potassium.* Together with sodium and chlorine, potassium belongs to the group of macrobioelements that (in contrast to phosphorus, calcium, and magnesium) are found mainly in fluids and soft tissues of the animal organism. Owing to its electron structure, potassium is one of the most mobile elements in nature. It is an essential microelement for plants, animals, and man. The biochemical and biological role of this cation is linked with that of sodium. They maintain the normal balance of water, osmotic and acid - base equilibrium, and equilibrium of metabolic processes in the cell, especially metabolism of carbohydrates. Potassium promotes cell growth and (together with calcium) plays a significant part in regulation of neuromuscular activity.

Deficiency of potassium in food, especially in ruminants, is very rarely manifested under normal feeding conditions. Large amounts of this element in fodder mis for calves can ert toxic action.

In humans, it has been demonstrated that potassium salts lower blood pressure. Potassium deficiency causes a whole series of disturbances in the organism, such as disturbances in work of the heart muscle, kidneys, digestive organs, respiratory organs, etc. *Hypokalemia* occurs with reduction of potassium intake, movement of potassium from the extracellular into the intracellular fluid, and increased loss of body fluids. A great deficiency of potassium can cause death. A surplus of this element more rarely leads to *hyperkalemia.*

*Phosphorus.* Like calcium, this essential macrobioelement is very widespread in nature. These two elements are antagonists and have much in common in metabolic processes. Among other things, they are directly linked with the same organic matter in bones.

The biochemical and biological function of phosphorus is essential to life, but adequate attention is not paid to this bioelement because it is present in nearly all foods. Apart from belonging to the group of basic biogenic elements, phosphorus has many functions in the organism, more than any other bioelement, for there are almost no significant metabolic reactions in which phosphorus is not involved.

In animals, phosphorus is among other things needed for growth, development, and formation of the skeleton; synthesis of milk components, i.e., production of milk; and production of meat, wool, eggs, etc. The lack of phosphorus in consumed food or a very pronounced deficiency of this element can be a cause of death in the first days or weeks of life. If an animal consumes fodder with a moderate phosphorus deficiency, it leads to the occurrence of so - called low - phosphate forms of rickets, which are manifested in slow growth. If *hypophosphatonemia* lasts for a longer period of time, growth stops and bone mineralization is disturbed.

In man, phosphorus is vitally important for normal functioning of the kidneys, proper work of the heart, and normal structure of the bones and teeth. It promotes growth and maintenance of the body in good condition, reduces arthritic pain, and is needed for transmission of nervous impulses. Vitamin D and calcium are extremely important for the proper functioning of phosphorus. Increased phosphorus intake can lead to *hyperphosphatemia*, usually in children.

*Sulfur.* Together with carbon, hydrogen, oxygen, nitrogen, and phosphorus, this essential macrobioelement belongs to the group of basic organic elements of which all living organisms are made. The biochemical and biological functions of sulfur (or compounds containing sulfur) are very diverse and numerous, since organic compounds with sulfur manifest their biochemical function through characteristics of the electron structure of this element, namely variable valence, ease of oxidation and reduction, and ability to form complex compounds with certain macro - and microbioelements, respiratory pigments, and enzymes with very significant biological roles.

The main limiting sulfur compound in consumed food is methionine. A partial or complete lack of methionine slows or stops growth and development of animals that have not yet attained morphofunctional maturity and lowers the productivity of animals raised for meat, milk, and wool. Large amounts of inorganic sulfur in the form of flowers of sulfur or sulfates in chickens and pigs retard the growth process and lead to rickets and gastroenteritis.

In humans, sulfur is especially important for healthy hair, skin, and nails. It helps maintain the oxygen equilibrium needed for proper brain functioning; assists the liver in secretion of bile; acts (together with vitamins of the B complex) on basal metabolism of the body; and forms part of the amino acids needed for tissue building.

**Microbioelements**. *Manganese.* Manganese is among the chemical elements essential for plants and animals. In man, it is present in the heart, liver, and kidneys. The biochemical and biological role of Mn is very significant because this microbioelement activates many enzymes of great importance for maintenance of the life and productivity of animals. Deficiency of Mn in consumed food is manifested in various symptoms, since it is directly or indirectly involved in the metabolism of basic nutrients with structural, energy, and biocatalytic roles in the organism. Symptoms of deficiency of this microbioelement are as follows: retardation of growth and development; irregularities in bone formation; reduced productivity; frequent nervous disorientation; etc.

In humans, manganese promotes activation of enzymes needed for proper utilization of biotin, vitamin $B_1$, and vitamin C in the organism; is needed for production of thyroxin, the main hormone of the thyroid gland, and for normal bone structure; plays a crucial role in digestion and utilization of food; and is important for reproduction and normal functioning of the central nervous system. A shortage of manganese results in ataxia (loss of muscle coordination). When greater amounts of this element are introduced into the organism, it acts as a poison, causing the disease known as *manganese madness*.

*Iron.* Iron is a necessary component of all plants and animals, including man. The biochemical and biological function of iron is very significant for maintenance of life and for reproduction. Iron plays an important part in transport of oxygen from the lungs to tissues, in transport of carbon dioxide from cells to the lungs, and in the process of respiration in the cell. Its function is maintained by many enzymes that contain it, without which there would be no life on Earth.

Manifested in retardation of growth, hypochromic anemia as a result of inadequate synthesis of hemoglobin is the main symptom of iron deficiency in all domestic animals.

For human beings, iron is a vitally important oligoelement. It is needed for formation of red blood cells (hemoglobin), myoglobin (the red pigment in muscles), and certain enzymes. Iron promotes growth, fosters resistance to diseases, and prevents fatigue and anemia. The amount of iron in the blood is increased in some pathological disturbances, but reduced in relation to the healthy organism in others. The monthly loss of Fe in women is twice as great as in men. It has been established that iron and calcium are most often deficient in the diet of women in America.

*Cobalt.* Cobalt is an essential chemical element as an integral part of vitamin $B_{12}$, although it takes part in biochemical processes in the form of a free ion. It is needed for growth of all living organisms and is of crucial significance for the red blood cells. Deficiency of cobalt in the food of animals is manifested in different symptoms because it takes part in many biochemical processes important for maintenance of animal life and productivity. In cattle and sheep, signs of cobalt deficit take the form of appetite and weight loss, exhaustion, and anemia. This form of anemia in humans is known as *pernicious anemia.* Toxicosis due to excess of Co occurs mainly in chronic form, and its symptoms depend on the amount of Co introduced. In humans, inhalation of Co leads to incidence of bronchial asthma, and exposure to Co salts has an especially unfavorable effect on the skin, thyroid gland, lungs, heart, and bone marrow.

*Copper.* Copper is an essential microelement for plants, animals, and man. It is a structural component of many enzymes significant for growth and development of animals, and for maintenance of their life and productivity. The biological significance of copper was first established experimentally in 1928 on rats fed only milk; the animals developed anemia, which was later alleviated by the action of copper from liver extract. Symptoms of dietary Cu deficiency (*hypocuprosis*) include anemia, impairment of growth and development, depigmentation of wool and hair, disturbances in synthesis of bone tissue (manifested in bone fractures), and degenerative changes of the blood vessels.

Among animals that continuously take in excessive amounts of Cu, the element accumulates in tissues, primarily those of the liver, with damage to its function. In the case of chronic toxicosis of animals, a longer period of time (several weeks or months) is needed for signs of poisoning to appear. Copper toxicosis rarely occurs in humans because copper and its salts introduced *per os* cause vomiting. It has been established that the spinal fluid contains twice as much Cu in persons suffering from *Alzheimer's disease*, which causes destruction of nerve cells in the brain.

Increase of copper content accompanies certain diseases, while others are characterized by its decrease. The organism loses the capacity to retain copper in the early stages of cancerogenesis, and copper is not involved in metabolism in the later periods. Copper in the blood is not bound with proteins in malignant forms of cancer. Accumulation of copper in the organism occurs in acute and chronic hepatitis and in cirrhosis of the liver. *Hypercupremia* is also characteristic of epilepsy.

*Zinc.* Like copper, zinc is an essential microelement for plants, animals, and man, taking part in many physiological reactions. Zinc behaves like a traffic policeman, directing and controlling the flow of processes in the organism and regulating enzyme systems and cells. The liver is the main organ in which metabolism of zinc takes place. This microelement is found in all cells and is also stored in the bones and in the prostate and testes among organs. Its metabolic and physiological role consists of activation of certain enzymes and participation in the formation of many metalloenzymes.

Zinc deficiency has an especially negative effect on fast - growing cells and tissues, and there are many possible symptoms of it. A shortage of zinc can result in hypertrophy of the prostate, atherosclerosis, and hypogonadism.

Zinc contributes decisively to resistance of the organism to all ailments, including malignant diseases. It also prevents decline in working capacity of the brain.

Symptoms of the rare instances of zinc poisoning in humans are similar to those of poisoning with other heavy metals. As with copper, extremely large amounts of introduced zinc salts are rejected by vomiting.

*Selenium.* The content of this metalloid is relatively significant in some 40 minerals, and soil of volcanic regions or arid and semi - arid areas (where it is not washed by precipitation) can sometimes have a high percentage of selenium. Few elements have had a history as interesting as that of selenium in study of the interrelationship of rocks, soil, plants, animals, and man. This element was for a long time considered toxic, until its addition to food was shown to prevent the occurrence of *Keshan disease* (endemic cardiomyopathy), which is characteristic of extensive regions in China with soil especially poor in selenium.

Selenium deficiency causes illness in cattle, sheep, goats, horses, pigs, and poultry. They most often suffer from the so - called white muscle disease or nutritive muscular dystrophy. The disease is manifested as weakness of the skeletal muscles, myocardial weakness, or a combination of the two.

Investigations have shown that Se plays three important roles in humans: 1) it is an anticancerogen; 2) it improves immunity; and 3) it protects the blood vessels. In addition to being an anticancerogen, Se also erts antiviral action. Organic compounds of selenium protect the organism against all types of ionizing radiation, including the radioactive kind. An unusually important role of selenium is its role in protection against poisoning by heavy metals (Cd, Hg, and Pb). Deficiency of selenium and other antioxidants is today held to be responsible for oxidative stress, decline of immunity, and occurrence of different diseases. Together with this, it considered to be a microelement essential in preventing the incidence of muscular dystrophy.

Selenium deficiency causes illness that goes by the general name of *selenosis*, while a surplus of selenium in consumed food (as has already been stated) erts toxic action. Poisoned animals experience blindness, salivation, a certain degree of paralysis, grinding of the teeth, respiratory disturbances, and death. Recent research indicates that development of the AIDS virus in humans can be caused by a deficit of selenium (E. W. Taylor et al., 1994, 1995; B. M. Dworkin, 1994; etc.).

*Molybdenum.* Molybdenum began to be studied more intensively from the time when it was established that a surplus of this microelement in animals causes changes that were subsequently referred to as *molybdenosis*. Molybdenosis occurs in many parts of the world and results from the presence of greater concentrations of molybdenum in livestock fodder obtained from natural sources or from intensive addition of Mo for the purpose of stimulating plant growth.

Molybdenum represents an essential element for animals, but the organism's need for it is minimal. Its biochemical function in the animal organism is manifested through enzymes of which Mo is a structural component. If all other conditions are met, Mo deficiency is rarely expressed, since the requirements of animals are satisfied through normal feeding. When present in greater quantities, molybdenum becomes toxic, especially for ruminants. Toxicity in the presence of a molybdenum surplus is manifested in the guise of exhaustion, anemia, depigmentation of the hair, and pain in the joints. In chronic cases, metabolism of the bones is disturbed, which leads to *osteoporosis*.

In man, molybdenum assists in the metabolism of carbohydrates and fats. It is a vital part of the enzyme responsible for utilization of iron. It helps prevent anemia and improves the general wellbeing of the organism.

*Iodine.* The amount of this essential microbioelement in terrestrial plants is correlated with the amount of it in the soil. Geochemical provinces in which water and food are poor in iodine as a consequence of iodine content in the soil (for example, mountainous regions of Bosnia, Serbia, and Slovenia, as well as the region of the Alps) are referred to as being goitrogenic.

Iodine - linked diseases are especially widespread in countries of the tropical zone of South Asia (Bangladesh, Myanmar, Indonesia, Nepal, Sri Lanka, and India) and are particularly prevalent in Vietnam (Fig. 2.39.). According to Dissanayake and Chandrajith (1999), 1.6 billion people and 50 million children are at risk from mental retardation and brain damage due to iodine deficits in food and water, and 100 thousand cretins are born every year. For this reason, the geochemistry of iodine in rocks, soil, water, sea, and air in relation to the incidence of iodine - deficiency diseases today represents one of the most interesting fields of research (Dissanayake and Chandrajith, 1999).

Metabolism of iodine is directly linked with synthesis and metabolism of thyroid hormones in the animal organism. Its deficiency in consumed food and drinking water lowers the concentration of iodine in the thyroid gland, with consequent decline in synthesis of thyroxin and triiodothyronine in the thyroid gland, which becomes enlarged in *endemic goiter*. On the other hand, large amounts of iodine in food for domestic animals are poisonous.

In man, two thirds of the body's iodine is found in the thyroid gland. Because the thyroid gland controls metabolism and iodine erts strong influence on its work, a deficiency of this mineral can result in slowing of psychic reactions, weight increase, and lack of energy. *Goiter* (*hypothyroidism*) occurs due to shortage of iodine.

*Fluorine.* Fluorine is present in the form of compounds (fluorides), which are widespread in rocks, but unequally distributed (Fig. 2.6.). Fluoride concentration in soil increases with depth. In soils of the USA, for example, fluoride content is 20 - 50 mg/kg at depths of up to 7.5 cm, but 20 - 1,620 mg/kg at depths of 0 - 30 cm. In regions rich in fluorine - containing minerals, groundwater can contain up to 10 mg/l of fluorides and more (for example, certain springs of water used for drinking purposes in Spain contain more than 20 mg/l of this ion). Fluorine belongs to the group of nutritive substances that have cumulative properties. It is introduced into the organism with food and water. As an essential element, it is found in the greatest amounts in the teeth and bones of animals and man, and traces of it are present in the thyroid gland and skin. Of total fluoride content, about 96% is stored in bone tissue.

It is estimated that in recent years more than 43 million people in China have suffered from dental fluorosis, which is mainly caused by the presence of fluorides in drinking water. This is particularly characteristic of groundwater. Many countries such as India, Sri Lanka, Ghana, and Tanzania have very pronounced incidence of dental and (in some cases) osteal fluorosis (Dissanayake and Chandrajith, 1999).

It has been demonstrated that the presence of fluorine in drinking water in concentrations from 1 to 1.2 μg/l significantly reduces the percentage of dental caries. In fact, it has been incontrovertibly established that this halogenic element erts protective action against dental caries, is essential for optimal growth and fertility of animals, and is very significant for maintenance of hardness of their skeletons. The teeth and bones (skeleton) of animals are damaged if the water they drink contains large amounts of fluorine over long periods of time (especially during growth). Fluorotoxicosis, so - called *chronic fluorosis*, generally is of a chronic nature. Fluorosis of the bones (*osteofluorosis*) is manifested in pain and stiffness in the joints, calcification of tendons and ligaments, and occurrence of *exostosis* and lameness. It later leads to *cachexia*, loss of appetite, slowing of growth, weight loss, and finally death.

In regard to its dissemination, course, complications, and consequences, *dental caries* represents the most massive and frequent non - infectious disease of man, one that is accompanied by significant socio - medical problems. Since 1945, fluoridation of drinking water has in many countries of the world been used or favored as a method of mass prevention of dental caries, and the results of studies in 20 countries show that the incidence of this disease was reduced on average by 30 - 90% as a result of it. Similar effects are achieved by fluoridation of salt, fluoridation of milk is also practiced, and tablets containing fluorine are sometimes used.

The first symptom of chronic fluorine poisoning is *dental fluorosis* or diseased dental enamel, which occurs as a consequence of consumption of water with fluoride content of more than 2 mg/l over a period of years. *Osteal fluorosis* is characteristic of geographic regions with extremely high fluoride content in drinking water. *Endemic fluorosis* occurs in regions where drinking water has fluoride content higher than 6 mg/l. *Osteosclerosis* occurs in 10% of adults if the daily intake of fluoride with water is more than 8 mg/l, and *paralytic fluorosis* occurs at concentrations of 20 - 80 mg/l or higher.

**Other Microelements.** Silicon, vanadium, chromium, nickel, arsenic, strontium, cadmium, and tin are elements that are found in the organism of animals and man, but whose essential nature has not been confirmed with certainty. In addition to those indicated, many other chemical elements are also present in animals and humans, depending on the geochemical composition and other factors of the environment in which they live. Some - like mercury, lead, and thallium - represent elements with highly toxic action.

*Silicon.* Silicon is among the microelements essential for growth and development of higher animals and man. In the animal organism and in man, the greatest amounts of silicon are found in connective tissue of the aorta, tendons, and trachea, and in other connective tissues.

Silicon is essential for growth and development of the skeleton of higher animals and man. Animals fed the same food but without Si are significantly smaller and finer - boned, many organs are atrophied in them, legs and crests are pale, and the skeleton is stunted owing to considerable slowing of its development. On the other hand, Si in large quantities is toxic.

*Vanadium.* Experimental data and studies with vanadium in the diet of rats and chickens confirmed that this microelement is essential for the tested animals. Vanadium is believed to be essential for humans also, since the organism of an adult man contains about 3 mg of it. It is a relatively toxic element.

*Chromium.* Extremely widespread in nature, chromium is present in soil, water, plants, and food, albeit in very unequal concentrations. It is an essential element for animals because its presence is needed for normal metabolism of carbohydrates and lipids. In humans, an increased need for Cr is felt where there is a reduction in tolerance for glucose. In contrast to other microelements, the level of Cr in human tissues declines with age, and the organism loses the capacity for normal metabolism of glucose, a condition known as *senile diabetes.* Chronic exposure of humans to dust of chromium compounds is correlated with increased incidence of lung cancer.

*Nickel.* This essential element is needed for growth and for resorption of iron. Nickel is non - toxic for the most part and is poorly absorbed from the lumen of digestive organs. It has been established that the amount of Ni in the human organism increases in certain pathological states, for example in patients with cancer, myocardial infarct, and thyrotoxicosis. Due to deficiency of vitamin $B_{12}$, Ni content is reduced in the blood of persons suffering from cirrhosis of the liver and chronic uremia.

*Arsenic.* Arsenic is found in nearly all soils, its content depending on geological composition of the terrain. It exists in minerals of many rocks, and its content in clayey media can be as much as 15 mg/kg and more. In slightly mineralized water, the concentration of this element ranges from less than 1 to 50 µg/l, more rarely to 200 µg/l (2,000 µg/l in Bad Dirkheimer Maxquelle and even 12,000 µg/l in the capped horizon in Eastern Wisconsin).

The toxicological role of arsenic is today amplified primarily by the anthropogenic factor (pollution). Of all elements after lead, it represents the greatest toxicological risk for domestic animals and humans. Cases of arsenic poisoning have been recorded in Southern Taiwan, Chile, Argentina, Mexico, China, West Bangal (India), and Bangladesh, and the governments of several countries have assigned priority status to research dealing with the influence of arsenic on health. In regard to toxicological characteristics, arsenic belongs to the category of poisons that accumulate in the organism. Chronic arsenic poisoning is manifested in loss of appetite, disturbances in the gastrointestinal tract, and weight loss. Skin diseases - including pigmentation, hyperkeratosis, and skin cancer - are the most typical symptoms of chronic exposure to arsenic through drinking water. Others include renal, gastrointestinal, neurological, hematological, cardiovascular, and respiratory symptoms. It has been established that small doses of As in the air increase mortality from lung cancer, and that a correlation exists between exposure to arsenic and cancer of the kidney, bones, and large intestine.

On the other hand, symptoms of arsenic deficiency in consumed food are evident in growth and many functions of the organism in domestic animals and include increased juvenile mortality. They also include changes in the content of bioelements in many tissues and organs of pigs and goats, as well as newborn piglets and kids.

*Strontium.* Strontium is found in the form of stable nuclides in the Earth's crust. In the organism of man and animals, it is concentrated in the bones and partially replaces calcium. Metabolism of strontium is very similar, but not identical, to that of calcium. Absorption, transport, and excretion of calcium are more efficient than in the case of strontium. It has been experimentally established that large amounts of Sr in consumed food negatively affect mineralization of the bones, even if adequate amounts of vitamin D are present in the food.

*Cadmium.* Cadmium is very widespread in nature, but considerable amounts of this microelement constantly enter air, water, and soil as a result of anthropogenic activity. In the human organism, it is stored primarily in the liver, kidneys, salivary glands, testes, and pancreas. Metabolism of Cd is characterized by defective work of the control mechanism for maintenance of homeostasis in the organism. With a half - life ranging from 12 to 30 years, cadmium is retained for a very long time in humans.

Many data suggest that Cd can be an essential element, but the amounts have not been established. The chemical reactions of Zn and Cd and their metabolic pathways are similar. However, while Zn is important as an essential microelement, Cd is better known for toxicity and metabolic antagonism to Zn and other elements. Introduction of a greater amount of Cd into the organism of man and animals leads to a wide range of metabolic changes. Severe toxicosis at high doses of Cd in humans is accompanied by serious, acute, and often fatal inflammations of the lungs. Hypertension or lung cancer (especially characteristic of persons who work in cadmium smelteries) can also occur.

*Tin.* It has been experimentally demonstrated that tin is essential for growth of animals and mammals, but the optimal and suboptimal amounts of this microelement have not yet been established. It is needed for proper growth of bones and connective tissue.

*Mercury.* After arsenic, mercury is the most important microelement in regard to toxicological significance. With its organic and inorganic compounds, mercury has a very wide range of applications. This being the case, mercury pollution of the biosphere takes many forms, with the possibility of acute and chronic poisoning by means of ingestion or inhalation. Animals are exposed to toxic action of Hg ions in air, soil, water, and food. Cases of professional, accidental, and medicinal poisoning have been known to occur in humans.

*Lead.* Lead is not an essential element of the living organism. It is considered to be one of the main pollutants of the environment and represents the most important cause of accidental toxicosis in domestic animals. Lead is a systematic poison that damages different tissues. With respect to its course, lead poisoning can be acute and chronic. Chronic professional lead poisoning is especially prevalent in humans. Along with cadmium and arsenic, lead is one of the leading carcinogenic elements.

*Thallium.* Thallium represents a toxic substance for all species of animals. The mechanism whereby this element erts toxic action is not known, but is presumed to involve interference with the metabolism of sulfur - containing compounds through binding with them, which happens in nearly all tissues in the organism.

### *Microelements in Rocks, Soil, and Water on the Territory of Yugoslavia*

Great differences in the content of individual microelements on the territory of Yugoslavia are a consequence of its diverse lithological composition and wealth of geological formations. The first information about the spatial distribution of microelements was obtained by geochemists, who since the 1950's have been engaged in study of their content in different geological environments, river sediments, soil, water, and vegetation for the purpose of finding concealed ore deposits. These investigations have enabled them to single out geochemical anomalies with elevated metal content and on a broader scale made it possible to isolate geochemical regions and geochemical provinces.

Two geochemical provinces stand out clearly in Yugoslavia: a Tertiary *lead* geochemical province, which encompasses the region of the *Inner Dinarides* and the *Serbo - Macedonian Mass*; and a Cretaceous - Tertiary *copper* geochemical province in the Yugoslav part of the *Carpatho - Balkanides.* These geochemical units and regions with ultrabasites are described below according to Z. Maksimovic and M. Rsumovic (1988).

The **lead geochemical province** includes significant deposits of lead and zinc, deposits of antimony ore, and a large number of smaller occurrences of these metals, as well as some deposits and occurrences of molybdenum, arsenic, mercury, and thallium. Genetically linked with these deposits, Tertiary magmatic and volcanic rocks are considerably enriched with many microelements, especially lead and zinc, but also antimony, bismuth, cadmium, and thallium. A large number of molybdenite - pyrite mineralizations occur in Mackatica and the wider region of the Surdulica eruptive massif. The rocks themselves sometimes exhibit molybdenum content as much as 25 times greater than average content in the Earth's crust, and this to some extent also applies to soil, water, and vegetation.

Numerous antimony mineralizations (sometimes accompanied by mercury) occur in rocks and soil of Western Serbia, between Koviljaca and Krupanj. Since volcanic rocks are widely disseminated within the lead geochemical province, elevated levels of heavy metals can be expected in soil and vegetation of large areas.

The **copper geochemical province** in Eastern Serbia extends across the Timok eruptive regions into the mountains of Bulgaria. It is marked by significant deposits of copper and a large number of mineralizations and occurrences of this metal. Genetically linked with deposits of copper ore, volcanic rocks occupy a large area in Eastern Serbia. The copper is accompanied by molybdenum, gold, selenium, and tellurium. The rocks are very poor in lead and (especially) chromium, which is one of their characteristics.

Within the framework of the Dinarides of Western Serbia and Western Bosnia (Bosnia and Herzegovina), there are large masses of ultrabasic rocks and serpentinites, which cover an area of more than 5,200 $km^2$. Soils developed on these rocks are considerably enriched with Mg, Fe, Cr, Ni, and Co. Because these rocks are extremely poor in other components, it is possible to expect elevated levels of Cr, Ni, and Co in water and food, but very low content of a whole series of biologically important microelements[63]. The ultrabasic rocks and serpentinites are carriers of chrysotile asbestos deposits (Korlace and Strugari) and many dispersed mineralizations and occurrences, which by contaminating air and water with minute hanging particles of asbestos can have carcinogenic effects.

We note that results of measuring the concentration of selenium in rocks, soil, food, and humans have shown that our country is deficient in this element[64]. Especially low average content is recorded in metamorphic schists (28 ppm) and Cretaceous - Tertiary formations (about 17 ppm) - rocks that are very widespread in Serbia - and in soils formed from them. The situation is similar with the loess formation in Vojvodina and along the southern rim of the *Pannonian Basin* (in which the content of selenium ranges from 5 to 50 ppm), a circumstance that is reflected in the concentration of this element in agricultural soil there (chernozem). Selenium levels lower than values average for the world has also been established in soils of lands along the Morava River and on the plain of the Zeta

[63] Studying the geochemical characteristics of alpinotypic ultrabasites of Serbia and Bosnia, Z. Maksimovic (1975) cites the following content of trace elements in peridotites: Cr, 260-5000 ppm (1722 ppm on average); Ti, 10-1250 ppm (341 ppm on average); V, 10-210 ppm (69 ppm on average); Ni, 750-4000 ppm (2008 ppm on average); Co 62-275 ppm (120 ppm on average); Mn, 300-1400 ppm (944 ppm on average); and Hg, 0.014 ppm on average.

[64] This does not mean that anomalies of the opposite sign do not exist. For example, galenites of the Rudnik deposit near the town of Gornji Milanovac contain as much as 87 g/t of selenium, and high levels of this element are present in phosphates around Bosilјgrad, Susevo, Kriva Lakovica, etc.

River. Such levels of this important element in cereals are reflected in the low selenium status in the human population of Yugoslavia. In view of the pronounced deficit of selenium, the possibility has been considered that its deficiency is one of the main etiological factors in endemic nephropathy (Z. Maksimovic, 1987), and increase in mortality from malignant diseases as a consequence also seems certain.

It is well - known that the territory of Serbia is characterized by many occurrences of chemically diverse types of slightly mineralized, mineral, and thermal waters. The natural medicinal properties of mineral and thermal waters have been exploited for a long time. However, the uncontrolled use of many of these waters doubtlessly entails negative consequences for public health, and it is one of the tasks of medical geology to divide a territory into regions based on the risk or positive influence of waters in them and make recommendations for the use of these waters. The importance of such scientific research is illustrated below by several examples of extreme concentrations of certain elements and other parameters.

1. A unique hydrological phenomenon in Serbia, the water of "*Djavolja varos*" ("Devil's City") on Radan Mountain in fact represents a mixture of dilute sulfuric and hydrochloric acid, a real poison for the human and animal organism. The water is characterized by extremely high potassium content (180 mg/l), content of metals (Al, Fe, Cu, etc.) above 1.5 g/l, and sulfur content of 2.63 g/l. It is also characterized by extreme acidity (pH 1.5) and high mineralization (15 g/l).
2. Saline (fossil) mineral waters in Serbia occur for the most part in the region of the former Pannonian Sea (Vojvodina) and its bays (Lestani, Ritopek, Valjevo, Mionica, etc.). For example, the mineral water in *Ovca* has high content of chlorine (9760 mg/l), sodium (6250 mg/l), $HBO_2$ (88 mg/l), strontium (29 mg/l), iodine (8.5 mg/l), bromine (28 mg/l), barium (19 mg/l), $Al_2O_3$ (7.0 mg/l), etc. Water from a borehole in Lestani is also similar to seawater (with mineralization of 18 - 20 g/l, bromine content of 45 mg/l, and iodine content of 5.0 mg/l).
3. Many other occurrences of groundwater are likewise not for oral use. We note several of them: a) the spring "*Suva Cesma 2*" near Prokuplje, which has very high concentrations of $SiO_2$ (730 mg/l), sodium (up to 1896 mg/l), $Al_2O_3$ (16 mg/l), and Ti (1.7 mg/l); b) as many as 56 mineral water occurrences in Serbia with fluorine content greater than 2 mg/l (the Yugoslav standard for drinking water is 1 mg/l), especially in waters of the *Serbo - Macedonian Mass* and northern part of Vojvodina, where it attains a maximal value of 25 mg/l; c) arsenic waters of the peak Crni Vrh northwest of Bor from an exploited deposit of copper ore have As content of up to 4.8 mg/l; and d) levels of $H_2S$ in waters of the Mataruska Banja spa and Slatina are high (21 and 15 mg/l, respectively).