TRACE ELEMENTS IN THE CREATION

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Formerly many of the chemical elements were regarded as being without biological significance. However, an increasing number of both metals and non-metals in minute quantities (trace elements) in the soil and diets, have been shown to have profound effects on plant and animal life. These chemical and physiological studies show the remarkable and complicated interlocking of the functions of many elements. Such can hardly be attributed to chance or evolution, but rather to the direction of the infinitely wise and almighty Creator, who has purpose in all the materials of his Creation.

Introduction

There has been a great increase in the amount of physical and chemical research, and extensive development of finer analytical techniques in the last half century. Much knowledge has been gained about the importance of very small concentrations of certain chemical elements; many of which were once regarded as scientific curiosities, and would have included perhaps the majority of the 92 elements usually listed.

The metallurgist has found the addition of small quantities of aluminum, copper, manganese, molybdenum, nickel, vanadium and wolfram to iron, as well as the earlier discoveries about carbon, cobalt and chromium, had profound effects in producing improved steels for various purposes. The same is true of numerous other alloys.

The effects of small quantities of certain elements on living creatures has long been known. Several of these, such as arsenic, antimony and lead, have chiefly proved poisonous. Wishful thinking through the ages of the medical value of gold, in spite of injections for arthritis, has been largely unfulfilled.

The main elements regarded as essential to plant and animal life are comparatively few. They are calcium, carbon, chlorine, oxygen, hydrogen, magnesium, nitrogen, phosphorus, potassium and sulphur, with the addition of sodium for mammals and man.

To this list must be added an increasing number of "trace elements," and these in very small quantities. The obvious first was iron, and later, probably for animals and man only, iodine.

So that those now regarded as required by both animals and plants, are copper, iron, manganese, molybdenum and zinc. To the list for animals, iodine and cobalt must now be added, and to that of most plants, boron and silicon. Probably more will follow for each group.

The quantities of the elements present in organisms, of course, vary. In man the total of these trace elements amounts to under 0.005%, and if iron is excluded the figure is under a fifth of that amount.

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The Element Iron

The element which, more than any other, has given man increasing control over his environment in this Iron Age, proves even more important in creation as essential for his very life. It is interesting to note that the ancient Romans realized the value of using solutions of iron salts for the treatment of anemia. However, to J. von Liebig went the honor of the great discovery of iron combining in the blood with oxygen.

The amount of iron in an adult human of 70 Kg is 3 to 4 gm or about 0.004% of the body weight. And 65% of this is in the blood, nearly all in hemoglobin. Here it is locked in a complex compound of which it comprises 0.335%. The structure of hemoglobin is one of the marvels of creation, and its function, through the reaction of the iron atoms in it with oxygen, is vital in respiration.

Hemoglobin consists of four units, each composed of a molecule of heme united to the protein globin. Perutz and his colleagues, using X-ray crystallography, found it consists of four polypeptide chains each containing a heme molecule. These chains interlock and form an ellipsoid of molecular weight 67,000. The heme molecule contains a single atom of iron combined with 74 other atoms; itself the center of four pyrrole rings, themselves arranged in a ring known as the porphin ring.

Iron is also found in human blood plasma in a number of other complex compounds, such as transferrin (siderophilin) which is a protein, one gram of which is able to take up 1.25 mg of ferric iron to convey to various tissues. Iron leaving the plasma is stored in bone marrow, the liver and the spleen. Storage compounds include ferritin, which consists of a protein of molecular weight 460,000 combined with 20% of its weight of iron. Another of these is the insoluble hemosiderin.

A number of other iron-containing compounds are apparently needed in the composition of various other creatures. One of these is an iron proteinate, hemoerythrin, which functions like hemoglobin, but is unlike it in structure. It is pale when reduced but red-brown when oxygenated, and is found in marine worms such as *Phaseolosoma* and the brachipod *Lingula*. Chlo-

rocruorin consists of a protein combined with a porphyrin containing iron. It is red in concentrated and green in dilute solutions, and is found in certain polychaete worms.

Enzymes are complex compounds formed only by living cells, and catalyse specific chemical reactions. Some 15 of them contain iron. One group of these compounds are oxidases, which are important for respiration and the oxidation of organic compounds in the blood. Catalase is one of the most powerful known, and consists of four iron atoms incorporated in a compound of molecular weight 248,000, obtained in a crystalline state from the liver. It can decompose 2,640,000 molecules of hydrogen peroxide per minute at 0° C.

Lactic or lactate dehydrogenase, used to oxidize lactic acid, has also been crystallized and found to contain iron. Pyrocatechase with a molecular weight of 82,000, includes two atoms of iron in its structure. Succinic dehydrogenase of molecular weight 200,000 has been separated with its four iron atoms. And there are other enzymes which contain iron, such as DPNH cytochrome C reductase, which contains several iron atoms in its molecule of weight 78,000.

Iron has also been found to be an essential component of the catalyst involved in the production of chlorophyll in plants.

The Element Copper

Copper was long thought to be nothing but toxic to organisms. The element amounts to but 0.0004% of the weight of the human body, or $\frac{1}{10}$ that of the iron present. Nevertheless copper is essential. The fetus, especially in its liver, is rich with a store of trace elements, particularly copper. Concentration of the element in late pregnancy is three times that of normal human blood which contains about 0.09 mg per 100 ml.

Anemia due to copper deficiency is morphologically indistinguishable from iron-deficiency anemia. The value of copper in the regeneration of the blood of children and animals has been demonstrated.

Lack of copper in the diet leads to bone deformity due to reduced calcium assimilation. Low levels of copper in food have resulted in poor growth, retarded milk production and impaired fertility in cattle. Degeneration of the nervous system, causing such diseases as "Sway Back" in sheep, and heart failure as "Falling Disease" in some Australian cattle, were traced to copper deficiency. This discovery led to six million acres of pasture being reclaimed by the application of copper.

Wool is largely composed of molecules of the protein keratin. Deficiency of copper in the food of sheep causes wool to lack crimp and to be steely or brittle. This is due to the absence of an enzyme containing copper, which controls the linking of these molecules.

Among plants, marked increases in growth occurred when copper was used with nitrogenous fertilizers. Application of copper to peat soils greatly improved their fertility. This also gave a higher copper content to the plants, with the consequent benefit to the cattle. Spectacular responses to copper by rice crops in Bombay State have also been reported.

Compounds important to some organisms include hemocyanin. It is a blue respiratory pigment found in the blood of crabs, squids and octopuses, which has copper in its prosthetic group. In some crustaceans it has a molecular weight of 360,000; in *Limulus* (horseshoe crab) it is 1,300,000; in the octopus, 2,000,000; and in *Helix* (land snail) 5,000,000. It is not a porphyrin like hemoglobin, but a copper proteinate.

Hemocuprin, a protein containing 0.34% copper has been isolated from human red blood cells and from plasma. Another protein, hepatocuprein, containing the same amount of copper, is found in liver. Some brain proteins contain copper, and these include cerebrocuprein I which has a molecular weight of about 35,000 with two atoms of copper.

Thus the element has been given important functions by God in His Creation. Furthermore a number of vital enzymes have been found to contain copper. Among these are A2-globulin (caeruloplasmin), monamine oxidase and δ-aminolaevulic acid dehydrase. Ascorbic acid (vitamin C) oxidase has been shown to contain six atoms of the element in its molecular weight of 146,000 or 0.26% copper. Tyrosinase contains 0.3% copper and laccase 0.34%.

Polyphenol oxidase contains 0.2-0.3% of the element as four atoms in the molecular weight of 100,000; while uricase has a single atom of copper in its molecule of the same size. Yeast, which contains a number of enzymes, shows 0.004% of its dry weight is copper.

The Element Zinc

Zinc is only 0.0001% of the body. Human blood contains about 0.75 mg per 100 ml and nearly all of this zinc is found in the red cells combined in the enzyme carbonic anhydrase. This compound has a molecular weight of 30,000 with one zinc atom. Its very important function, vital to respiration, is to catalyse the splitting of carbonic acid into water and carbon dioxide.

Zinc is also present in alcohol dehydrogenase, which contains four or five atoms of zinc in its molecule of weight 150,000. And it is found in the enzymes: alkaline phosphatase, carboxypeptidase, lactic dehydrogenase and liver glutamic dehydrogenase.

The zinc content of viable human sperm is very high. It is necessary for the proper functioning and development of the male reproductive organs. Thus the element is another Divinely appointed essential to the survival of life.

Deficiency in the element particularly affects fruit, legume, cereal and grass crops. Sugar cane yields in Natal, South Africa, were greatly increased by the application of zinc salts to deficient soil.

The hormone insulin is well known as necessary for carbohydrate metabolism. It is a protein having a relationship with zinc. While active material can be obtained free of the metal, it is present in the crystalline form used, which has a molecular weight of 6,000. The pancreas, in which it is formed, is rich in zinc. In treating diabetes, protamine zinc insulin added to insulin produces the advantage of prolonging the effect of the injections.

The Element Manganese

Manganese is another element thought unlikely to have a beneficial function in the life process. It is only about 8 millionths of the dry matter of many plants, and 0.00016% of the human body. Yet it is found in many enzymes, or as an active part of the prosthetic groups. These include arginase, pancreas-nuclease, phosphoglucokinase, hydroxylamine reductase and uricase.

In chickens, pigs, dogs and rabbits it is reported that a deficiency of manganese has resulted in malformed bones. An excess or a deficiency in the case of cows caused a 20% reduction in gestation. Egg production was also decreased by a deficiency. It is thus important for growth, bone formation and fertility, while it also assists hemoglobin regeneration.

Plants in many cases show remarkable benefit from the presence of traces of manganese. It is involved in the activation of enzymes concerned with the formation of chlorophyll, and all chlorophyll tissues contain the greatest concentration of manganese. Over 50% increase in the carotene (the precursor of vitamin A) content of soya bean leaves occurred where the manganese deficiency was made good.

"Gray Speck" is a disease occurring in oats where the element is deficient. The addition of manganese to apparently healthy potatoes doubled the crops. In South Africa the production of certain apple and pear orchards was increased by 450% by the application of manganese. Similarly a 100% increase in wheat yield is reported after spraying with manganese sulphate solution.

Application of manganese in correct quantities produced an increase of 18% in the yield of tomatoes, and a 28% increase in their vitamin C content. It also diminished by 15% the undesirable protein zein in maize and increased the other proteins.

It has been found that molluscs from very different parts of the world are rich in the element. The freshwater bivalve *Anodonta cygnea* in particular has a large amount, chiefly in the liver and gills. The element is in the form of a metallo-organic complex (Mn + protein) which earlier investigators thought had a respiratory function, but this is not so, although its use is still to be discovered.

The Element Cobalt

Cobalt long seemed to have no relevance to life. Yet the discovery of its function in the Creation led to curing "Phalaris Staggers" in sheep and cattle in vast areas of land in Australia, Russia and elsewhere.

Cobalt is important as being the essential and single metallic atom of the 183 in the cobalmin or vitamin B12 molecule, and amounting to 4% of the weight. The quantity in the normal body is exceedingly small, being about 80 μg altogether. Intake of this remarkable compound need be only 1 μg a day, but without vitamin B12 nervous disorders and anemia occur.

Cobalt is synthesized by micro-organisms in the gastrointestinal tract of ruminants, from the element supplied in the diet. It is the anti-pernicious anemia factor in liver extract used clinically, and was isolated in 1948 as a red crystalline compound by E. L. Rickes and his co-workers. Administration of small amounts of cobalt salts stimulates erythropoieten production.

Cobalt is also required by the bacterium *Rhizobium*, which fixes nitrogen in the roots of leguminous plants. The use of cobalt salts thus produced a 60% increase in a soya bean yield.

The Element Molybdenum

Molybdenum, one of the heavier elements, is required by living tissue in only minute quantities, and is less than 0.00001% of man. It is important in the development of healthy teeth.

In molybdenum-deficient soil, "Whip Tail," a growth abnormality in cauliflower, develops. This is curable by applying a pound of sodium molybdate per acre. Where deficiency of the element was removed, the vitamin C content of vegetation doubled.

For animals and man molybdenum is extremely important as a constituent of the enzyme xanthine oxidase, which contains 0.03% of the metal. Zanthine oxidase is particularly plentiful in the liver and intestines. It catalyses the final reaction in the formation of uric acid, a waste product of protein metabolism, before its excretion by the kidneys.

Molybdenum is also important for fixation of nitrogen in plant nutrition, as part of the mole-

cule of the enzyme nitrogen reductase. This catalyses the reduction of nitrates from the soil to nitrites, as a first step in the building up of proteins. So another element, long regarded as of biological insignificance, has been given vital functions in the Creation.

Elements Nickel, Cadmium and Silver

Nickel is not normally of biological interest except as causing toxicity. There is some evidence, however, that the element could replace cobalt in the treatment of certain cattle diseases. Remarkably Laevastu and Thompson in 1958, found in their sea water investigations that plankton contain twice as much nickel as the higher marine plants, and ten times the amount found in fish and molluscs they examined. It is not yet known if this element is essential to their life, or if it exists in them as organic compounds, or if the creatures are, for some reason, accumulators of nickel. Certainly its presence in such quantities in this essential food for so many kinds of fish is noteworthy, and thus constitutes another wonder of the Creation.

Cadmium is generally also regarded as a toxic element, and small amounts have been found damaging to the testes. However, it has a value in that it is found in the prosthetic groups of the enzymes prolinase I, arginase and urease.

Silver is found in minute quantities in the thyroid gland and tonsils, but its function there is unknown at present. The element is used in medicine in colloidal form in association with the proteins, and silver ions have a valuable germicidal effect.

The Element Vanadium

Vanadium is one of the less common elements, but has been known since 1830. It was certainly not usually regarded as of biological significance, but it has been found to be an essential constituent of sea squirts. Vanadium chromogen is a pale green pigment in the blood cells (vanadocytes) of these creatures, the Ascidiidae and Perophoridae, and appears to have a respiratory function. The evolutionist has an insurmountable problem here to explain the presence of vanadium rather than iron in the blood, for effecting this action.

Vanadium is also found in some fungi. In the alga *Scendesmus obligatus* it is beneficial if not an essential nutrient. It also promotes growth and nitrogen fixation in the microbe *Azobacter*, acting as a catalyst.

In mammals vanadium has beneficial effects on teeth and in hemopoiesis. It also reduces chloresterol levels and inhibits some cancers.

Incidentally vanadium is found in coals and petroleum as well as in its ores. These deposits may well have developed from plant and animal tissue. In Italy, soot has proved a valuable commercial source of the element.

Elements Lithium, Sodium, Magnesium

Lithium, the alkali metal allied to sodium, and the lightest of all metals, is not yet known to be essential in the biosphere. In fact it has been found to be somewhat toxic in California citrus groves. The plant families Ranunculaceae and Solanaceae act as accumulators of it. However, the lithium ion can replace sodium in nerve tissue. It has also recently been found that lithium chloride changes the state of brain activity, reducing aggressive behavior in treating maniac-depressive psychosis.

Sodium, like chlorine with which it is usually combined as sodium chloride or common salt, is essential to animal life, and is ninth in abundance in the human body at 0.15%. Plants, however need it as a trace element, especially the algae *Anabaena cylindrica* and the desert shrub *Atriplex vesicaria.* It can help replace potassium in many cases, and root crops such as beet especially benefit from it, as do celery and asparagus.

Magnesium is not really regarded as a trace element either in animals or plants. It represents about 0.6% of the dry material in a typical plant and about 0.05% of the human body, or some twelve times the amount of iron present. In the latter it is half in bones and half in cells, where it is an essential part of many enzymes including phosphoglucomatose.

However, as an example of the wonderful planning of the Creator, who gave magnesium a vital role in the life cycle, it should be mentioned here in one particular respect. That is as the single metallic atom among the 137 forming the molecule of chlorophyll which has a similar chemical structure with its pyrrole rings to that of heme in blood, but at 892, a much smaller molecular weight. The compound is the green material in plants essential to photosynthesis and thus their growth, and ultimately, to maintain life in man and beast. Thus in another sense "all flesh is grass."

Elements Aluminum, Boron, and Others

Aluminum is always present in soil, and is third in order of abundance at 7% of the Earth's crust, chiefly as a constituent of silicate rocks. It is present in only minute quantities in living matter, and was not regarded as relevant to life. However, its use in water cultures showed the element's value, as it greatly increased the yield of millet and maize. There is also some evidence that it functions in catalysts in mammals.

Of the non-metallic trace elements, boron has long been known in a number of compounds. Of these only boric acid or its salts, as anti-

septics or preservatives, have had a biological significance. Its concentration in typical dry plant material is only about three parts per million, but its absence from soil can prove disastrous.

Boron deficiency has been shown to lead to "Brown Rot" in swedes* and to "Heart Rot" in economically important sugar beet, to stunting and malformation in cauliflower, and to rotting in celery, which needs more of the element than most plants. A number of other economic plants develop rusts and mildews in the absence of sufficient boron. Also many pollen grains will not germinate in its absence.

On the other hand, application of suitable concentrations of boron have markedly increased the yields of such widely differing crops as apples, coffee, lucerne and mangolds (beets). It is particularly valuable to sugar beet, increasing the yield, and proving necessary for the translocation of sugars from the leaves. This is probably effected through compounds known as boron chelates, in which the element is united to certain organic molecules. Another valuable property of the element is its beneficial influence in the production of certain vitamins of the B group, namely thiamine and niacin.

Ascarian blood, as well as containing the remarkable vanadium compound mentioned above, contains unusually large amounts of chromium, manganese, molybdenum, niobium, tantallum, titanium and tungsten. The presence of these elements is not merely due to local deposits, but is general. Their functions are probably catalytic. Niobium, like vanadium, may be used for low oxygen levels. Some creatures apparently use selenium and tellurium as electron acceptors. It has been suggested that gallium and scandium found in some plants act as catalysts in certain enzyme structures. Thus from these observations a further number of trace elements appear to have been given a function in the Creation—to the confusion of the evolutionist!

Elements Iodine, Chlorine, Fluorine

The Greeks of 2000 years ago used the ash of sponges (now known to contain iodine) in the successful treatment of goitre. Iodine is found in man to be but 0.0004% of his weight or four parts in a million and thus only a hundredth part of the iron present. Yet a deficiency leads to the disfiguring and disabling goitre found in many races. This disease called hypothroidism is due to failure of the thyroid gland to produce the hormone thyroxine.

The thyroid gland contains 0.06% iodine which is bound to protein in the cells. The presence of iodine in the thyroid gland was found by Baumann in 1895, soon after Murray had discovered the therapeutic effect of the thyroid extract of animals. Thyroxine was crystallized in 1919 by Kendall in the U.S.A., and synthesised in Britain by Harrington and Barger in 1927. This compound has 35 atoms, four of which are of the vital element iodine, designed by the Creator for the healthy functioning of human and mammalian life.

Of the other elements in the halogen group, the function of bromine is yet unknown. Chlorine is present in small quantities in living matter, being 0.15% of the body, and is not regarded as a trace element. It occurs in organisms in the form of common salt and other chlorides, and as an essential constituent of the gastric juice. In tropical conditions it can be insufficient in diets. As is well known its deficiency is met by salt licks for sheep and cattle.

The other halogen, fluorine, is only a minute part of the weight of man. Normal bones and teeth have 20 to 30 mg of the element per 100 gm of ash, with more in the dentine than in the enamel surface. A low level of fluorine in water is linked with tooth decay, but if the concentration is one part per million up to two parts in the water the incidence is very much lower.

Excess results in debilitating fluorosis with excessive calcification and discoloration of the teeth. This is another case of the delicate balance between excess and the amount necessary to health. Strangely tea and sea fish are the only other sources of this element in diet apart from the fluorides in drinking water.

Elements Silicon, Sulfur and Selenium

Silicon is the second most abundant element in the Earth's crust, its oxide being estimated to form 55% of it as rock and soil. It is found in varying quantities in different plants, being present in the macro quantity of about 1.2% in maize.

While apparently unnecessary to man and not essential to all plant growth, silicon is valuable in giving mechanical strength to most plants. It is present especially in the connective tissue of mammals and forms a high proportion of the ash of feathers, probably giving them rigidity.

Sulfur is an essential constituent of a number of proteins, and, at 0.25%, is in greater abundance in the human body than sodium, chlorine or magnesium.

Selenium has a number of properties similar to sulfur, but is normally regarded as valueless or toxic. The presence of selenium in grasses and other plants produces "Alkali Disease" in cattle, characterized by particularly abnormal development of the feet. Yet it appears that vitamin E and selenium are part of certain pro-

*A "swede" is a Swedish turnip, *Brassica campestris*, var. *napobrassica*, much used in Europe as a domestic vegetable and also for winter cattle feed.

tein structure. Also selenium as well as zinc, is essential for the proper functioning of the testes.

Injections of vitamin E (αtocopherol) or selenium prevent "White Muscle Disease" in sheep. Ten mg of selenium given monthly produced a marked increase in the growth rate of some Aberdeen Angus calves. Rats were also protected from necrotic liver degeneration, and chickens from exudative diathesis by minute quantities (a few micrograms daily) of this mysterious element.

Discussion

The above observations, if studied in detail in original source papers, show that a fine balance must be obtained in trace element concentration, in order to secure plant and animal health, and even to maintain life. There is a danger of overdosage, most elements in excess of certain limits having toxic effects, manganese in particular being so to man.

Trace elements may also act against each other, and in some cases one may assist another. But it is exceptional for one to be replaced by another with benefit to the living organism.

Important differences of course exist between the requirements of plants and those of animals. Thus iron is less important to the former, but essential to mammals, and the same applies to cobalt. Plants also hardly need iodine or sodium, but mammals require both.

On the other hand, boron certainly, and silicon probably, are necessary for plants, but so far do not appear to be essential to animals. Also, of course, different plants and different animals have needs of trace elements of different kinds and in different quantities.

It should be remembered too that elements function in many different ways in both animals and plants. The health of plants and animals in a particular area has been found by biogeochemical investigators frequently to be due to the presence or absence of certain trace elements in the soil of that district.

So the condition of certain plants in particular, causes them to act as indicators (to the advantage of prospectors) of the presence of certain trace elements. Thus the infinite wisdom of the Almighty Creator is in part manifested in the marvelous interlocking functions of so many elements, in such low concentrations, in His Creation.

What of the numerous elements not mentioned above, either as macro or micro constituents of organisms? Some writers, yet without confirmatory observations, claim that such elements have an effect in the biosphere.

Certainly ions as well as compounds of the trace elements named can catalyze some organic reactions. They influence enzymes by producing a cationic climate of clouds of ions. It is known already that cobalt, copper, iron and manganese form chelated (claw-like) compounds with amino acids. Examples are copper diglycinate and the cobalt-cysteine complex.

It may well be that ions of the other elements have similar effects, but this has yet to be confirmed up to the time of writing this paper. Arsenic, bromine, chromium, gadolinium, germanium, tin and titanium are among those for which definite functions are yet unknown.

Conclusions

Perhaps two remarks may be added in closing this paper. One is that deficiencies and toxicities connected with the distribution and existing quantities of certain elements may be regarded as departures from the original creation, pronounced "very good" by God in Genesis 1:31. Such differences could well have been occasioned by the Fall of Man and subsequent global catastrophes such as the Flood.

The second point to be made is that of hope (expectancy) that in a new Earth under the beneficient, wise and righteous rule of the Lord (II Peter I, 13), all imbalances will be removed.

Finally as we view the importance of these trace elements in the Creator's economy, we may well concur with Evelyn Underhill in her poem, "Immanence":

"I come in the little things,"
Saith the Lord,
"Not born on morning wings
Of majesty, but I have set My Feet
Amidst the delicate and bladed wheat
That springs triumphant in the furrowed sod."

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