INORGANIC CONTAMINANTS: OCCURANCE AND SIGNIFICANCE OF CHEMICAL ELEMENTS WITH SPECIAL REFERENCE TO PLANTS

Bernd Markert
Fliederweg 17, D-49733 Haren, Germany

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Summary

An overview of the occurrence, distribution and contamination of inorganic chemical substances in various environmental compartments and the rates of flow between these will be given. In an ecosystem the pathways and location of elements can be influenced in a specific manner by the organisms, e.g. by selective uptake and enrichment of the inorganic substances. Special emphasize is placed on the distribution and activity of chemical elements in plants in relation to their occurrence in the earth crust, their beneficial effects to living organisms and their acute or chronic toxicity to living systems. From here a so called "reference plant" could be developed, which allow a direct comparison of individual plant species by standardizing them against the reference plant. A Biological System of the Elements (BSE) has been established, which take inter-elemental correlations, the biological function and the uptake form of individual elements into consideration. If the relationship in between these functions of elements is out of balance the inorganic contamination might have a toxicological effect.

1. Introduction

Current studies in the global circulation of carbon, sulfur, and phosphorus and studies on trace gases show how important knowledge is of the global circulation of these substances between the atmosphere, the biosphere, hydrosphere, and the geosphere. The earth's crust can be viewed as a natural reservoir for all of the chemical elements of the biosphere. More than 99% of the total mass of the earth's crust consists of only eight of 88 naturally occurring elements. It is made up of 46.4% oxygen, 28.15% silicon, 8.23% aluminum, 5.63% iron, 4.15% calcium, 2.36% sodium, 2.33% magnesium, and 2.09% potassium. Of the eight most common elements in the earth's crust, oxygen is the only non-metal. The other 80 elements of the periodic table make up less than 1% of the total

(Figure1).

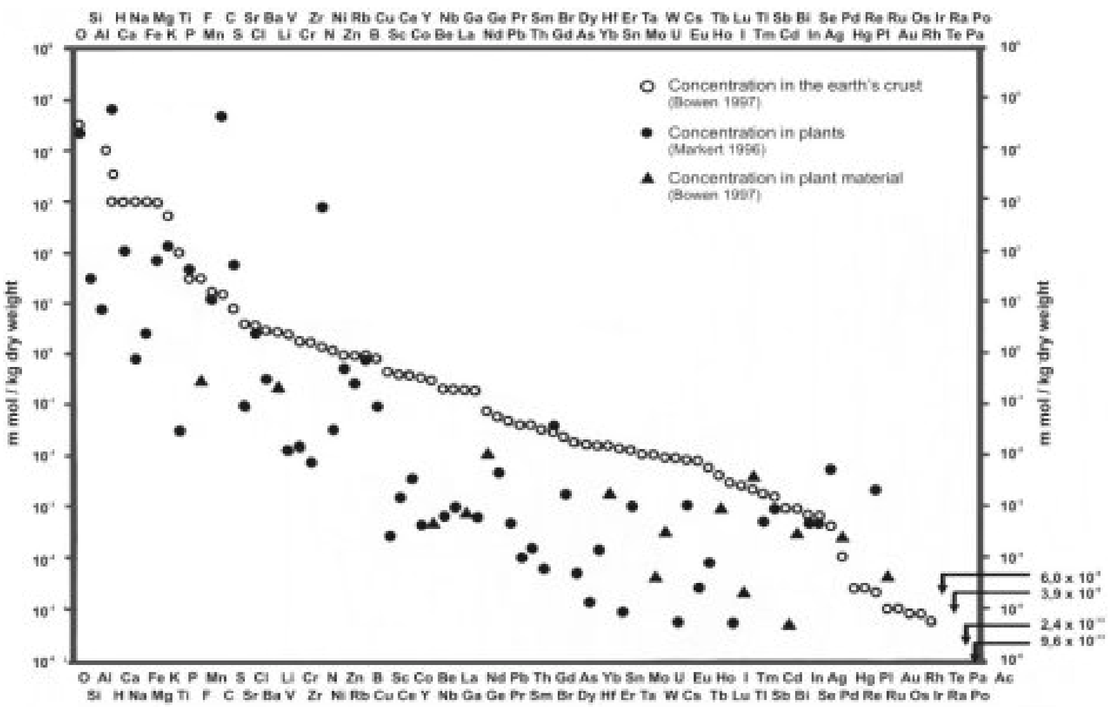

Figure1. Concentration of 82 naturally occurring elements (excluding the noble gases) in plants in the earth's crust (Markert 1996). The elements are listed in decreasing order based on their presence in the earth's crust.

The largest portion of the fresh weight of living plant organs (those showing active metabolism) consists of 85-90% water on average. The dried matter of the plant is made up mostly of the following elements: carbon (44.5%), oxygen (42.5%), hydrogen (6.5%), nitrogen (2.5%), phosphorus (0.2%), sulfur (0.3%), and the alkali or alkaline earth metals: potassium (1.9%), calcium (1.0%), and magnesium (0.2%). Thus, in contrast to the earth's crust, the main mass of organic life consists largely of non-metals (Figure2). The nine elements listed are also called macroelements because they occur in vegetation in increased amounts. There are also microelements, which are present in plants in reduced concentrations and which are vital for most plants. The microelements are chlorine (2000 mg/kg of dry material), silicon (1000 mg/kg), manganese (200 mg/kg), sodium (150 mg/kg), iron (150 mg/kg), zinc (50 mg/kg), boron (40 mg/kg), copper (10 mg/kg), chromium (1.5 mg/kg), molybdenum (0.5 mg/kg), and cobalt (0.2 mg/kg).

Macroelements and microelements are plant nutrients which are necessary for the growth and normal development of the plant; their function cannot be replaced by any other element. Therefore they are essential (Figure 3). For this reason, macroelements and microelements are also called macronutrients and micronutrients, respectively. The division of the periodic table into essential and non-essential elements does not always seem to be useful, because there are numerous exceptions in the plant kingdom, especially when one compares higher plants with lower ones. For example, calcium, boron, and chlorine are not considered essential in some bacteria and fungi, nor are sodium and silicon in higher plants.

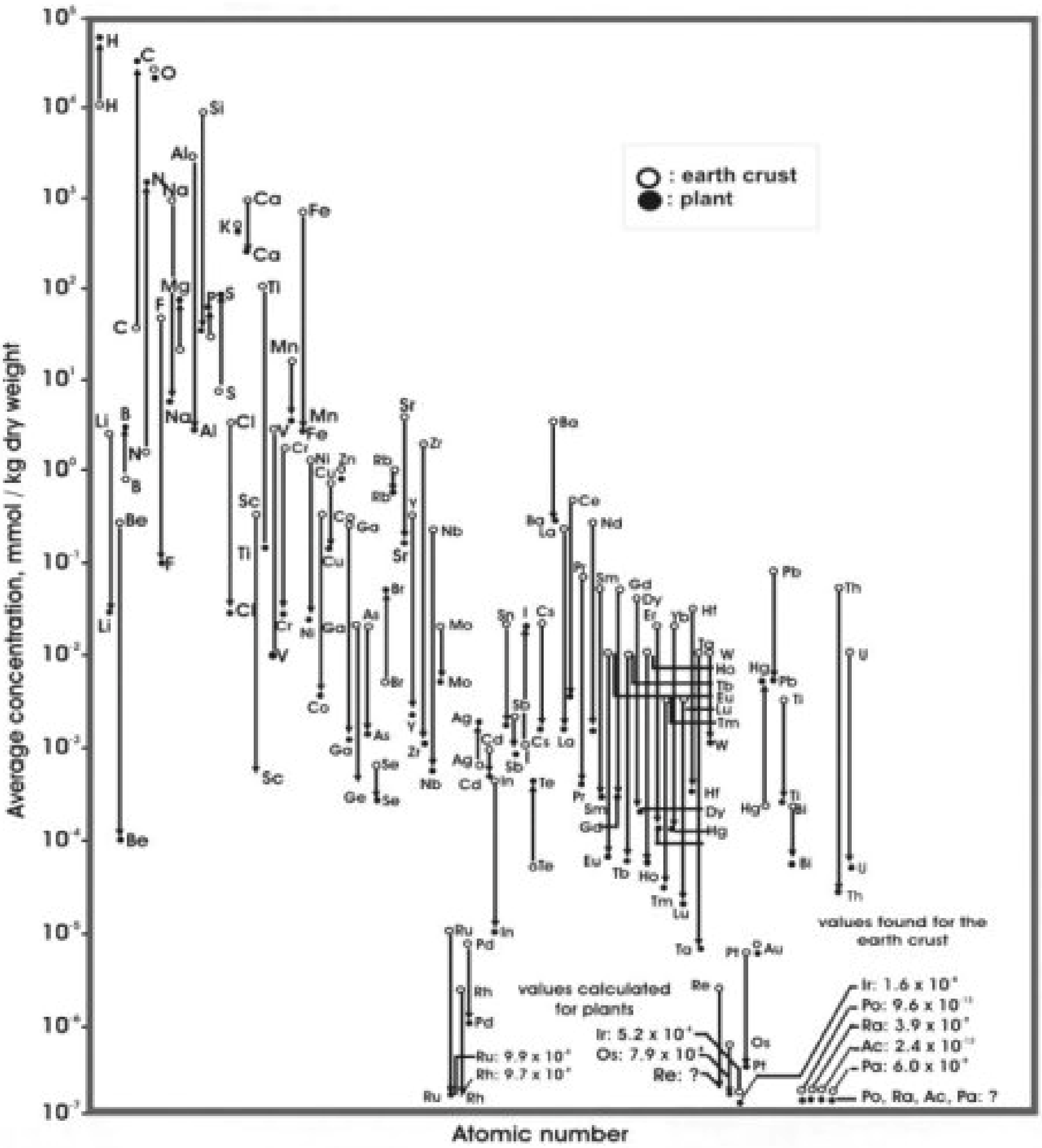

Figure 2. Average concentration of 82 naturally occurring elements in plants and in the earth's crust as a function of their atomic mass (Markert 1996).

In addition to the macronutrients and micronutrients just discussed, another series of chemical elements is also present in plants. For speculation of a possible physiological function during evolution of these inorganic substances Figure 4 shows the molar masses of element concentrations in a plant compared with the molar masses of the average concentrations of individual elements in the earth's crust.

Most of the element concentrations are arranged along the median line of these two components of the concentration. On the one hand, this shows that the extraterrestrial genesis of the elements is reflected in the earth's crust as well as in living biomass. On the other hand, it shows that individual elements have attained particular significance during the evolution of the earth and especially in modern biological life.

These are the elements in Group I in Figure4, namely C, H, O, K, Ca, Si, Na, Fe, P, S, N, Mn, B, Zn, Cu, Ni, Cr, Co, Cl, V, F, Rb, Sr, Ba, Ti, and Al. All but the last five have a vital (essential) function in at least some groups of organisms. Even the last five elements, Rb, Sr, Ba, Ti, and Al, are assumed to have an essential function, although this cannot be described in any more detail currently.

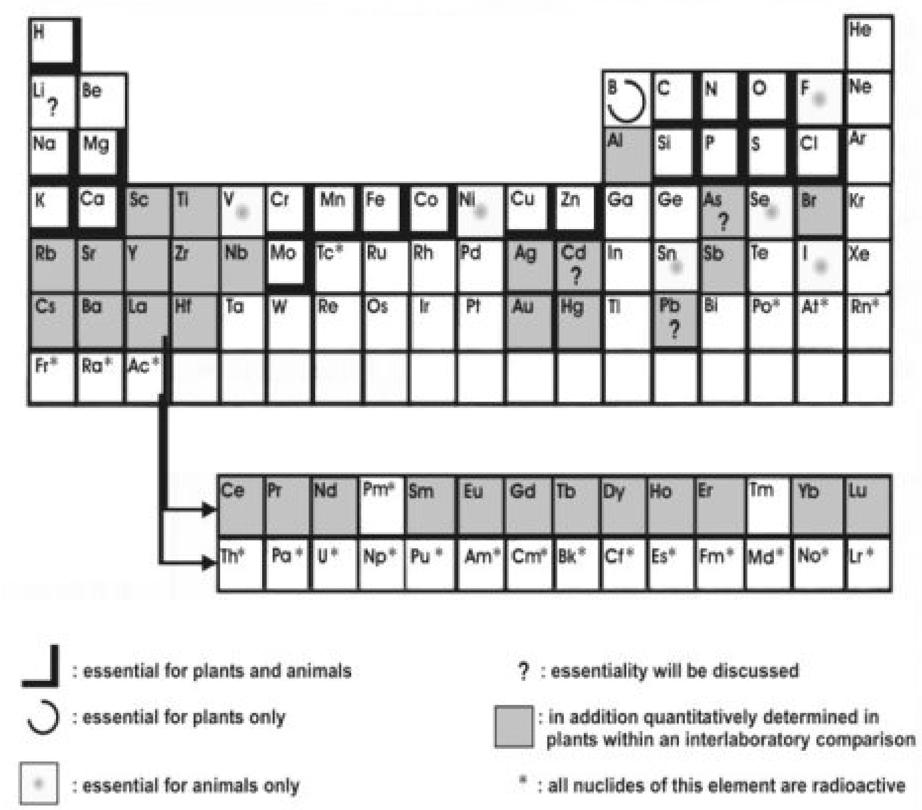

Figure 3. The periodic table of the elements with indicators on elements that are essential and that have been quantitatively determined (Markert 1996).

Group II includes those elements which, although some of them do have known essential functions (I, Mo, Se, and Sn), are characterized by their high toxicity, usually even at low concentrations. This is particularly true for the heavy metals Pb, Cd, As, Tl, Hg, etc. Group III includes elements which have not succeeded in moving beyond a passive role in the earth's crust in the course of evolution, nor in integrating themselves into an active component of living organisms.

Group III consists of the lanthanides and the platinum metals in particular. This evolutionary concept of a selection of chemical elements for the generation of living organisms led to the creation of a first Biological System of the Elements (BSE), which will be described later. Just like the division into essential and non-essential elements, the classic division into microelements and macroelements described above, which strictly refers to the physical mass of an element within the organism, has undergone considerable modification in modern plant, animal, and human physiology. The list of the macroelements had to be expanded for certain groups of organisms.

For example, the element silicon is considered to be a macro-element for horse-rails and diatoms. Also, element-specific and organism-specific accumulation processes frequently occurs due to their specific habitat: sodium, bromine, and chlorine are enriched by many halophytes; copper, nickel, zinc, lead, cadmium, and other heavy metals are taken up in increased measure by metallophytes.

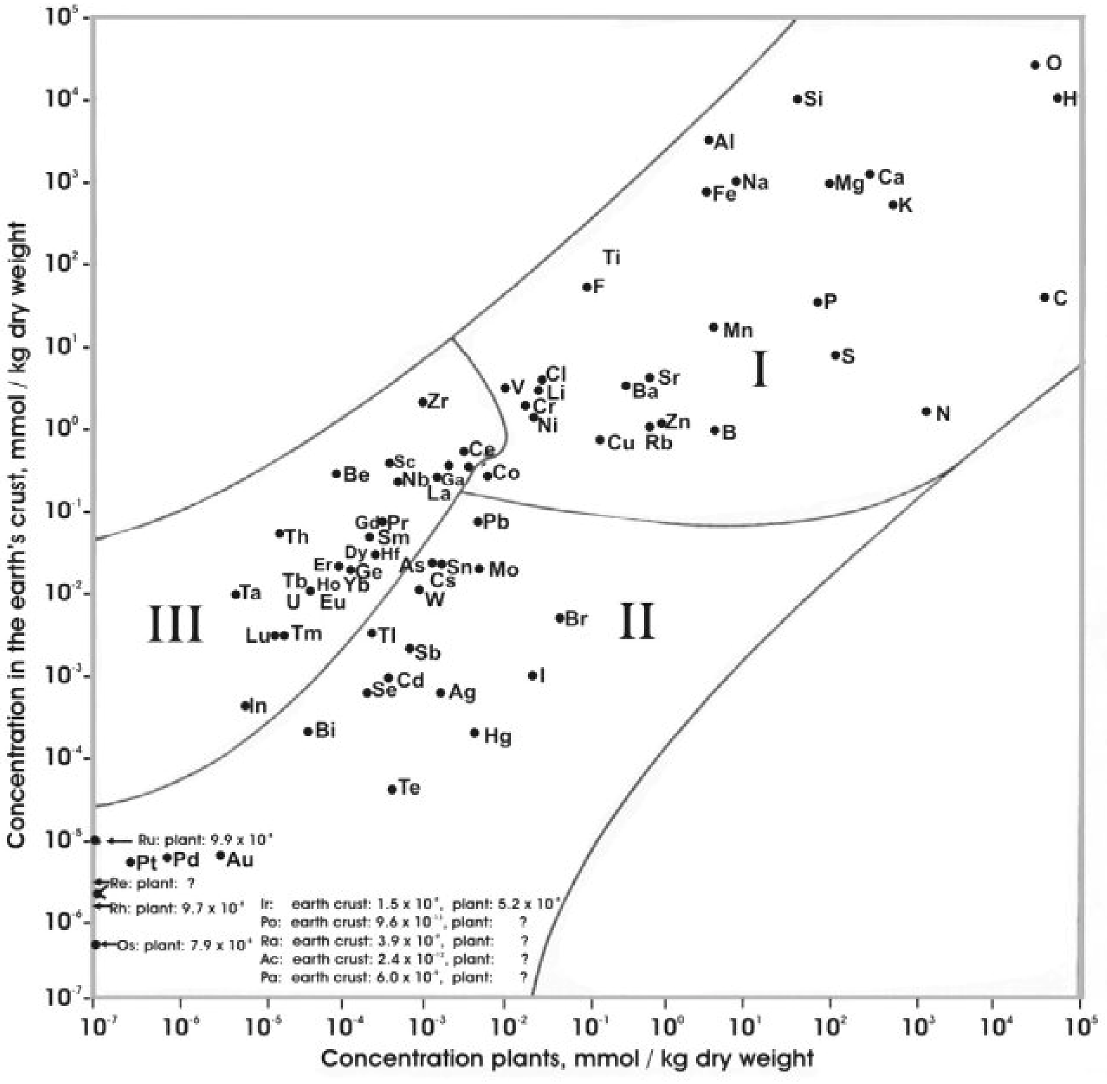

Figure 4. Average concentration of chemical elements in plants in relation to the average concentration of elements in the earth's crust (Markert 1996). All data are in mmol / kg dry weight.

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Biographical Sketch

Bernd Markert, PhD, became a full professor of Environmental High Technology of the International Graduate School Zittau, Germany, in 1994 and has been the director of this institute until 2003.. His professional interests include the biochemistry of trace substances in the water/soil/plant system, instrumental analysis of chemical elements, eco- and human-toxicological aspects of hazardous substances, pollution control by use of bioindicators and technologies for waste management, environmental restoration and remedial action on soils.