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A review of recent activity in the United States

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Either an overabundance or a deficiency of trace metals in the food chain can ultimately affect adversely the health of livestock and man. Increasing interest in the United States in the distribution of metals in the environment and in metal pollutants has led to widespread interdisciplinary research sponsored by governmental, private and academic groups concerning the availability of trace elements for absorption by plants and animals, and the effects of trace elements throughout the food chain. The state of the art and the needs for research are reviewed by interdisciplinary committees in the National Academy of Sciences and in many government agencies. Research is encouraged through contracts and grants awarded by federal and state agencies and the National Science Foundation to universities for studies of specific metals, specific diseases and correlations between metals and health in specific geographic areas. Effects on the environment of coal-fired power plants, the mining and processing of metals, asbestos, and phosphate, and the disposal of industrial and nuclear wastes have also received much attention in the past few years.

Introduction

Nutritionists, veterinarians, toxicologists, and physicians have long been aware of the benefits of certain elements and the hazards of others to the health of plants, livestock, and man. Within the past 10 years, however, a rapidly expanding interdisciplinary group of scientists, including geochemists and biochemists, has begun working together on the formidable problems now recognized in areas vital to health. Naturally occurring elements of the geochemical environment and man-made pollutants have both attracted scientific and medical interest. Background information and baseline studies are needed to help distinguish those pollutants that should be controlled more stringently from those whose control might be relaxed.

This paper reviews the early beginnings of the study of environmental geochemistry and its relation to health in the United States and attempts an overview of recent research in this field by Federal agencies and universities of the United States. The coverage is of necessity incomplete and represents only a sampling of the voluminous research that has been reported in the past 10 years.

History of interdisciplinary cooperation

Early cooperative efforts between medically orientated scientists, geochemists and biochemists included several symposia on environmental geochemistry in relation to health and disease. These symposia, organized by geochemists, who had found anomalous concentrations of metal in the environment, emphasized the need for contact between the appropriate disciplines to investigate the availability and effects of trace elements along the food chain from rocks to man (Cannon & Davidson 1967; Cannon & Hopps 1971).

The major credit for encouraging and supporting environmental geochemistry and health studies in the United States goes to the Research Applied to National Needs (R.A.N.N.) portion of the National Science Foundation (N.S.F.). R.A.N.N. provided early support to National Academy of Science Committees and university projects. Numerous other grants were provided to individual researchers.

Other government agencies later expanded environmental geochemistry and health programmes of in-house research and extended grant or contract support to state, university and private groups. Major sponsoring agencies are the U.S. Public Health Service, the Environmental Protection Agency, the National Cancer Institute, the Energy Research and Development Administration, the U.S. Bureau of Mines and the U.S. Geological Survey.

A particularly important series of annual conferences on Trace Substances in Environmental Health was begun on 10 and 11 July 1967, with N.S.F. support, by D. D. Hemphill at the University of Missouri Environmental Health Center in Columbia, Missouri (Hemphill 1967–1977). In 1969 the programme was expanded to include papers on the geochemical environment. This conference provides the outstanding annual review of this subject in the United States, and regularly attracts top environmental and biomedical scientists from many countries.

The need for a society to bring together this interdisciplinary group of scientists for purposes of communication and for the development of a common identity resulted in 1972 in the formation of the Society for Environmental Geochemistry and Health (S.E.G.H.), whose interests range from Earth and environmental sciences on the one hand to biomedical and nutritional sciences on the other. S.E.G.H. recently became an affiliated society of the American Association for the Advancement of Science (A.A.A.S.). The Society's official publication, *Interface*, a quarterly which was first published in February 1972, carries substantive articles, critical evaluations, book reviews and newsletter items of interest to a widely divergent membership of nearly 500 (S.E.G.H. 1972).

In 1969, the Subcommittee on the Geochemical Environment in Relation to Health and Disease (G.E.R.H.D.) was established under the U.S. National Committee for Geochemistry in the Earth Sciences Division of the National Academy of Sciences. This Subcommittee sponsored a symposium at the A.A.A.S. meetings in 1970 (Cannon & Hopps 1972) which appraised the occurrence and availability of trace elements (especially Fe, Mn, and Se) in the environment as they affect the health of livestock and man. Another symposium was held at the New York Academy of Sciences in 1971 (Hopps & Cannon 1972), which dealt with the availability of trace elements to plants and animals (emphasizing areas of excess and deficiency), animal and human requirements, degenerative diseases in relation to environment, and problems in sampling and methodology. From 1972 to 1974 the Subcommittee conducted a series of week-long workshops, each with 40–50 participants, which brought many new ideas to the attention of diverse groups of scientists not generally knowledgeable in each others' fields. A brief description of each of these workshops follows.

The Asilomar Workshop, held in 1972, primarily surveyed the information available on the amounts of 11 elements (F, I, Cr, Li, Cd, Zn, Pb, Se, Te, Cu and Mo) that occur naturally in rocks, soil, and water; their increase in the environment caused by man's activity; their uptake and concentration in plants; their absorption and retention by animals and man; and their effects on health and disease (Cannon 1974). The Capon Springs Workshop, held in 1973, considered 8 more elements (Be, Mg, Mn, Ni, Si, Sr, Sn and V) in the same way and reported on

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several case studies (Mertz 1977). The Captiva Island Workshop, held in 1974, applied previously compiled information about specific elements and geochemical conditions in the environment toward the identification of causal relations and associations with certain forms of cancer, cardiovascular disease and urolithiasis (Hopps 1978).

In 1975, G.E.R.H.D. initiated panels, each with from six to ten specialists to study special topics. Four such panels now functioning are: (1) the Panel on the Geochemical Environmental and Urolithiasis, which evaluates evidence relating the existence of a 'stone belt' in the U.S.A. and the conditions conducive to the formation of renal stones in man; (2) the Panel on Aging and the Geochemical Environment, which reviews and evaluates existing evidence of environmental effects on ageing; (3) the Panel on the Geochemistry of Water in Relation to Cardiovascular Disease, which considers the chemical components of water that may relate to cardiovascular diseases in man; and (4) the Panel on the Trace-Element Geochemistry of Coal Resources Development Related to Health, which studies possible health-related effects on man from the mining, processing and use of coal.

In addition to the committees of the National Academy of Science that have just been described, considerable research on the geochemical environment as related to health and disease has been initiated by government agencies and supported by Federal funds in universities throughout the United States.

Distribution and availability of trace substances in the natural environment

Trace substances in soils and plants

The breakdown of rocks to soils and the availability of trace elements to forage and foodstuffs create a variability in the natural environment that may affect animal and human health. Studies of the distribution of trace elements in soils and plants in the United States by the U.S. Geological Survey have included analyses of soils collected at 50 mile (*ca.* 80 km) intervals throughout the conterminous United States (Shacklette *et al.* 1971*a*, *b*, 1973, 1974), a study of the variation in the trace-metal content of soils and sagebrush of the Powder River Basin of Wyoming (Connor *et al.* 1976), and a study of Li in sediments and plants of the Basin and Range Province of the western United States (Cannon *et al.* 1975). Background values were established for 147 landscape units (Connor & Shacklette 1975). A survey of metals in foodstuffs throughout the United States has not yet been released. Another major source of background data of an areal nature is the large-scale sampling of soils and plants for prospecting carried out in mineral districts, such as the Coeur d'Alene district (Gott & Cathrall 1977), and in wilderness areas.

Members of the Agricultural Research Service and Soil Conservation Service at the U.S. Plant, Soil and Nutrition Laboratory, Ithaca, New York, are studying the chemistry of trace elements in soils as related to their concentration in plants and their availability to animals. These studies of availability proceed logically from the dependence on the composition of rock substrate to the effect of soil-forming processes, to interactions between elements, and to the plant composition (Hodgson 1969; Hodgson *et al.* 1971). The distribution of Se in the natural environment at levels toxic and deficient for animals has been studied throughout the United States by Kubota *et al.* (1967). Their data have been compared with heart disease and cancer occurrences by Shamberger & Willis (1971) and Shamberger *et al.* (1975). Allaway (1968) has

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suggested that Se concentrations in animal and human diets be deliberately maintained at 0.1–2 parts/10^6 by additions to soil, feed and salt and by interregional shipment. Current studies include environmental effects on the availability of major elements to plants, and the soil–plant–animal cycling of Se, Cr and other essential trace elements. The interactions between metals as they affect uptake by plants have received particular attention at the Agricultural Research Service in Beltsville, Maryland (Lagerwerff & Biersdorf 1971).

The Laboratory of Nuclear Medicine and Radiation Biology at the University of California at Los Angeles campus has also been active in this area and has reported on comparative toxicities and interactions between metals in plants (Berry 1977); and the potential toxicity to plants of trace elements in fossil fuels (Berry & Wallace 1974).

D. J. Horvath at West Virginia University has investigated the availability of Mn and Fe to plants and animals (Horvath 1972).

A comprehensive and interdisciplinary project on Mo in the environment was sponsored by N.S.F.–R.A.N.N. for several years at the University of Colorado and Colorado State University. The project was under the leadership of W. R. Chappell, and the geochemical aspects of the project were under the direction of D. D. Runnells (Runnells *et al.* 1975; Jorden & Meglen 1973). In general, the study showed that Mo is not readily released from unmined deposits, but is made available to the environment through mining. The effects on the health of animals and human beings exposed to excessive amounts in the environment in Colorado appeared to be minimal.

An interdisciplinary symposium on Mo was held in Denver in 1975 and was sponsored by the E.P.A. and the N.S.F. The papers ranged over the entire spectrum of research involved in understanding the complex environmental role played by this metal. Of particular interest were reports of field studies conducted at the University of California at Davis of Mo-induced Cu deficiency in young cattle, and experimental studies at the University of Missouri, which showed that the amount of S in the feed determines whether Mo alleviates or aggravates Cu deficiency. Participants from the Colorado Mo project presented evidence that Mo reduces the net Ca transport into bone and described the physiological adaptation to an excess of Mo that occurs when such an excess is ingested over several generations. The complete proceedings of the symposium have been published in two volumes (Chappell & Peterson 1976, 1977).

Trace substances in water

The chemistry of drinking water is closely related to that of the rock substrate and directly affects the health of man. The geographic distribution of certain elements in water supplies and the effect of treatment on the trace element content has been studied by the U.S. Geological Survey (Barnett *et al.* 1969; Durfor & Becker 1964; Engberg 1973). Samples of raw and finished waters have been analysed for the past 19 years through a monitoring programme conducted by the Federal Water Pollution Control Administration (Kopp 1970). The U.S. Environmental Protection Agency (E.P.A.), which also conducts surveillance programmes, has recently updated the U.S. Public Health Service drinking water standards (Federal Register 1975).

A workshop sponsored by the National Academy of Sciences found that water samples from several major cities contain disease-carrying agents, and that excessive amounts of metal, notably Cu and Pb, are common. The workshop's recommendations include the production of maps of specific drainage basins with more trace-element analyses, the separation of Ca and Mg

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in maps of water hardness, the collection of data on specific ground water aquifers, and the acquisition of information on the anions associated with metals in water.

Geochemists at Pennsylvania State University have been conducting research on the amounts and behaviour of heavy metals dissolved or suspended in soil moisture and in ground and surface waters (Back & Langmuir 1974). The effect of treatment and distribution systems on trace element content has been studied at the University of Pittsburgh (Andelman & Shapiro 1972) and the geochemical behaviour of Se in natural waters has been studied at the University of Georgia (Howard 1972). These projects are only a sample of the large amount of research on water being conducted in the United States.

Geochemical studies related to disease patterns

Studies of the geographical distribution of elements in the natural geochemical environment as related to the incidence of major diseases in the United States have so far shown suggestive but not definitive causal relations. A geochemical study in Georgia by the U.S. Geological Survey of plants and soils in areas of high and low heart disease rates showed no definitive relation (Shacklette *et al.* 1970); however, that study did not report on Cd concentrations. High cancer rates in certain areas of Maryland (Cannon 1975), correlated positively with increased concentrations of Cu, Cr and Pb; both the incidence of cancer and the metal concentrations are higher near highways. In cooperation with the Phoenix, Arizona, Medical Center, the disease incidence on the Gila River Indian Reservation was compared with the geochemical environment (Sievers & Cannon 1974), and it was found that low levels of Cr in the soils and produce could not be related to diabetes. Current studies by investigators at Brigham Young University, however, show lower Cr in diabetics than in non-diabetics on the reservation (R. M. Izett 1977, personal communication).

A study, designed to support epidemiological investigations under way at that time, was made by the U.S. Geological Survey of the geochemistry of rocks, soils, water and vegetation in the state of Missouri. The principal result of the study is a series of geochemical maps and other compilations that should be useful in future epidemiological research (Tidball 1971; Erdman *et al.* 1976*a*, *b*). Only limited relations between soil chemistry and human mortality rates could be established (Tidball & Sauer 1975).

The National Cancer Institute has recently published an atlas of maps showing cancer mortality by county and economic area for many types of cancer from 1950–1969 for both whites and non-whites (Mason *et al.* 1975, 1976). An interdisciplinary proposal to study the geochemistry of the soils, plants and water in the counties having the highest and lowest incidences of cancer and heart disease has not been implemented.

The Environmental Protection Agency has compared metals in air pollution with cardiovascular disease rates in 77 cities and has found a positive correlation with Pb but not with Cd or Zn (Hunt *et al.* 1970). Voors (1971) of the National Institute of Health found negative correlations between arteriosclerosis and both water hardness and Li in 100 cities.

The Department of Environmental Health, University of Cincinnati, has related the development of bone cancer to trace elements in various soils and plants and to the use of snuff (Baumslag & Keen 1972). The same department has related the concentrations of metals in bituminous coals to the incidence of pneumoconiosis (Sorenson *et al.* 1974).

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Hazardous substances released to the environment through man's activity

Government agencies and committee research

The realization that toxic metals and other hazardous substances are released from motor vehicles and from smelters and other industrial plants has led to the funding of many studies of the geochemistry and biochemistry of hazardous elements. In 1970, the National Academy of Science (N.A.S.), Division of Medical Sciences, with support from the E.P.A., formed the Committee on Biologic Effects of Atmospheric Pollutants. In 1973, when this committee's mandate was expanded, it was renamed the Committee on the Medical and Biologic Effects of Environmental Pollutants. Although dominantly biomedical, the Committee and its several subcommittees have consulted geochemists and environmentalists in the preparation of their reports on chemical elements and substances that occur both naturally in the environment and as man-made pollutants. Reports on the following inorganic substances have been prepared: asbestos, fluorides, Pb, Mn, Cr, NH_3, As, CO, H_2S, V, Ni, Cl, Se, Cu, Fe, nitrous oxides, platinum-group elements and Zn.

The Committee on Research Needs on the Health Effects of Fossil Fuel Combustion Products is considering the health and enviromental effects of power-plant byproducts, and cost of measures that could reduce the risks.

The N.A.S. Commission on Natural Resources also has several committees, such as the Committee on Radioactive Waste Management, the Committee on Energy and the Environment, the Committee on Chemistry of Coal Utilization and the Committee on Scientific and Technical Assessments of Environmental Pollutants, concerned with hazardous conditions in the environment. The International Environmental Programs Committee serves as U.S. National Committee for the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions. The Committee provides consultant service to the U.S. Department of State and other federal agencies, maintains contacts with international organizations and national institutions in other countries concerned with environmental problems, and undertakes special studies of critical environmental problems having an international impact. The Committee on Accessory Elements is studying the redistribution of accessory elements and compounds that would result from future mining and utilization of coal deposits, uranium ores, oil shales, iron ores and non-bauxite aluminium ores, such as as anorthosite and aluminium-bearing clays.

The U.S. E.P.A. is properly involved in studies of the effluent from coal-fired power plants and smelters. Results include trace-element studies of three power plants (Schwitzgebel *et al.* 1975) and the Helena smelter (U.S. E.P.A. 1972). The latter study showed greatly increased concentrations of metals near the smelter. A study was also made of roadside gradients in atmospheric concentrations of Cd, Pb, and Zn (Creason *et al.* 1971). The U.S. Department of Agriculture studied metals in soils and plants and their uptake by persons living near a smelter (Lagerwerff & Brower 1974). The N.S.F. has supported a study of metals in the environment at the Oak Ridge National Laboratory. This research has resulted in studies of Cd in plants (Francis & Rush 1973) and, through a workshop, a comprehensive report on Cd in the environment (Fulkerson & Goeller 1973). Extensive annotated bibliographies have been compiled on As (Copenhaver *et al.* 1973*a*), Hg (Caton *et al.* 1972) and Cd (Copenhaver *et al.* 1973*b*). A report on the environmental impact of Cd has been compiled by the National Institute of

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Environmental Health Sciences (Fleischer *et al.* 1974) and one on criteria for recommended standards for occupational exposure to Cd has been prepared by the National Institute of Occupational Health and Safety (1976).

Review papers on the geochemistry of Hg (U.S. Geological Survey 1970) and of Pb (Lovering 1976) in rocks, soils, stream sediments, water, plants and the atmosphere were published by the U.S. Geological Survey. Several environmental studies have been made in the vicinity of power plants (Anderson & Keith 1976, 1977); Cannon & Swanson 1975). Trace element concentrations around power plants are not nearly as high as those around smelters; smelters emitting Cd are particularly hazardous to health.

University research

An ambitious 7 year interdisciplinary study of Pb was sponsored by N.S.F.–R.A.N.N. at three cooperating universities: Colorado State University, the University of Missouri at Rolla and the University of Illinois. The studies both individually and jointly have resulted in several comprehensive publications including *Environmental lead contamination*, edited by H. W. Edwards (1974), and *Lead in the environment* (Boggess & Wixson 1977). Similar studies have been made for Zn, Cd and Cu as related to lead mining, milling, and smelting in southeastern Missouri (Wixson & Bolter 1971). Research findings have been used by industry for pollution control and by state and federal agencies for the establishment of new guidelines and standards (Bolter *et al.* 1972). Similarly, studies of Pb at the University of Illinois have been followed by studies of Cd and Zn in plants (Miller & Koeppe 1970; Root *et al.* 1975).

Heavy-metal contamination related to mining and smelting in the Coeur d'Alene district, Idaho, is being studied by an interdisciplinary group at the University of Idaho (Johnson *et al.* 1975).

A study of the origins, fate, and control of Hg in water and in the biogeochemical environment was also funded by the N.S.F. at Stanford University (Stanford 1973). The project has contributed much valuable information on the occurrence of Hg in a mercury district, its binding and eventual release by iron sulphide, the biological formation and decomposition of methyl mercury, and its migration into the food chain (Burkstallar *et al.* 1975; MacNaughton & James 1974).

Departments on two campuses of the University of California have been actively involved in studying the effects of toxic levels of metals on plants. The Department of Soil Science and Agricultural Engineering at Riverside has reported significant findings related to the uptake of Cd by a large number of plant species from soils of different chemical and physical properties (Page & Bingham 1973). Present studies by the Laboratory of Nuclear Medicine and Radiation Biology at Los Angeles involve environmental studies of a coal-fired power plant and a geothermal test site (Berry & Wallace 1974). Plant uptake and translocation of ^{210}Rb and ^{109}Cd to leaves have been studied at the University of Missouri and the University of Tennessee (Hemphill & Rule 1975). A study at the California Institute of Technology has shown that aerosol Pb introduced into the food chain by foliar deposition from atmospheric pollution has increased the body burden of Pb in the average person in United States to more than four times normal (Elias *et al.* 1975).

Scientists at the University of Florida are studying several problems of elemental pollution. The processing of phosphate in central Florida causes F toxicity in livestock, vegetables, citrus fruits and man. Despite efforts by the companies, fluoride problems prevail (G. K. Davis 1977,

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personal written communication). The use of water hyacinths and other water plants as indicators of metals, such as Hg, in water is being studied at the University of Florida by R. L. Shirley. The uptake of metals by algae and their possible use in removing metals from polluted water is being studied at the University of Missouri at Rolla (Jennett & Wixson 1975). Arsenic as a water pollution hazard and its existence in detergents has also been studied at the University of Kansas (Angino *et al.* 1970).

A direct effect of mining on the health of man has recently caused concern: that of asbestos mining and processing. The hazard has been studied by several research groups including the staff from Mount Sinai School of Medicine of New York City University (Rohl *et al.* 1977) and by the Consumer Protection and Environmental Health Services of the Department of Health, Education and Welfare (Dixon *et al.* 1968).

Essential trace substances and effects of excesses and deficiencies in animal and human health

At the lower end of the food chain the availability, essentiality, nutritional value and toxicology of trace elements to animals (including man) require and are receiving serious consideration in the United States. In addition to the interdisciplinary workshops and committees described previously, many strictly biological and medical studies are being made. The N.A.S. Assembly of Life Sciences has many committees directly or indirectly involved in these areas of study, including the Food and Nutrition Board and the Committee on the Biological Effects of Ionizing Radiation (Assembly of Life Sciences 1976). The Committee on Toxicology advises government agencies on broad matters of policy involving toxicology, recommends interim environmental exposure standards, suggests specific toxicology testing or research, and advises on or participates in field studies on toxicity problems. The Committee on Safe Drinking Water, in conjunction with the E.P.A., has investigated the adverse effects on health attributable to contaminants in drinking water, to form a scientific basis for revision of national drinking water regulations. A 950 page report on *Drinking water and health* has recently been published (National Academy of Sciences 1977).

The N.A.S. Commission on Natural Resources includes a Committee on Animal Health (National Academy of Sciences 1976) and one on Animal Nutrition.

There are many federal agencies with strong statutory interest in the subject. The National Institute of Environmental Sciences (1976) appointed a task force to review human health and the environment, and to point out research needs. The task force was interdisciplinary and included scientists from other government agencies.

The Energy Research and Development Administration and Battelle-Northwest sponsored jointly a symposium on 'Biological implications of metals in the environment' at Richland, Wash., in 1975. The symposium included papers on the microbial transformation of radionuclides and natural trace metals in the environment, the forms in which they occur, their availability to plants and animals, and their effects on health. The collected symposium papers are available from E.R.D.A. (Hanford Life Sciences Symp. 1975).

The U.S. E.P.A. has established Health Effects Research Laboratories, which are issuing a series of publications on metallic elements. An example is a study published in 1975, *Molybdenum a toxicological appraisal* (Friberg *et al.* 1975). E.P.A's Community Health and Environmental

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Surveillance System is a nationwide surveillance of community health and its relation to changing environmental quality (Shy & Finklea 1973). Special studies have been made of the effects of Cd on health as relating to urban air pollution (Hammer *et al.* 1971).

The National Institute of Arthritis Metabolism and Digestive Diseases has recently awarded a contract to the University of Florida to study urolithiasis in the United States with a major emphasis on the relation between trace elements in the environment and the incidence of kidney stones. The university studies suggest that low Mg in coastal plain sediments may be a contributing factor. The University of Florida has for many years studied areas of highly organic soils in Florida that are commonly deficient in Cu, Co, Zn and Mn and excessive in Mo. This imbalance affects vegetable crops and the animals grown in these areas (Harris 1967; Davis 1969).

The U.S. Department of Agriculture has established a Human Nutrition Laboratory at Grand Forks, N. D., to determine the essentiality and requirements of trace elements for human beings and factors that affect those requirements. The research has established the essentiality for Cu, Zn, Mn, Cr, Ni, S, F and Sn in experimental animals and has proved or postulated the essentiality of many in man (Nielson 1974; Sandstead 1975); other studies have investigated the effects of metal deficiencies; Ni, Pb and Cd toxicity and interactions with other elements (Sandstead 1976).

Ganther *et al.* (1972) at the University of Wisconsin have shown that Se has a strong protective effect against hazardous metals.

An International Symposium on Trace Elements and Human Disease was held in Detroit, Michigan, in 1974. The Symposium emphasized the nutritional and metabolic importance of trace elements, such as Zn, Cr, Cu and Mn. Se is identified as an integral part of the enzyme glutathione peroxidase, thus establishing its essential role in man. The complexity of Fe and Zn availability, the importance of interactions between elements, and the toxicities resulting from Hg, Cd, Ni and Pb are also reviewed by the participants in a two-volume monograph published by the Nutrition Foundation (Prasad 1976).

A study in the school of medicine at Washington University under the direction of H. Mitchell Perry has shown a relation between long-term Cd feeding and high blood pressure in rats. Additions of Se or Zn inhibit the Cd-induced hypertension (Perry *et al.* 1977).

The Environmental Center of the Kettering Institute in Cincinnati, Ohio, has been studying the toxic effects of Cd and Pb and their interaction with essential elements (Murphy *et al.* 1975).

Many other papers by University scientists on the effects of trace metals on animal and human health have been published in the volumes of the University of Missouri conferences on Trace Substances in Environmental Health.

Conclusions

In the past 10 years, interest has increased greatly in the distribution and availability along the food chain of trace substances in the natural environment and also in the contributions of metals by man's activity.

Although research in many areas is inadequate and overall geochemical sampling in our vast country is impossible, the recent studies described have not altered greatly the conclusions from previous observations that (1) excesses of certain ions in drinking water and (2) increments of pollution from metal in air and water appear from our studies so far to have greater effects on

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health and disease than natural variations in metal content of unpolluted soils and vegetation in the United States.

The National Academy of Sciences has more than a dozen interdisciplinary committees and as many subcommittees made up of geochemists, biochemists, nutritionists, veterinarians, and medical scientists. These investigators collate available information to establish essentiality, optimum levels, tolerance limits, and regulatory decisions for trace substances in the biosphere and to consider possible causal effects of the environment on health and disease. The participants are drawn from Federal agencies and universities in the United States. Basic research is reported in journals and symposia publications each year in the United States in such volume that review of the achievements by individuals and references to their work is not possible in this paper, but the information provided may be a starting point for readers who wish to learn how far we have come or to plan the research that is so urgently needed.

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