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Public Health and Geological Processes: An Overview of a Fundamental Relationship

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2.1 Public Health Definitions and Approaches

The health of human populations is highly dependent on a range of environmental determinants, including those relating to geologic materials and processes on our planet (Fig. 2.1). There is a clear continuum of geochemical cycles and pathways for uptake of elements into plants, animals and humans. Indeed, the optimal functioning of the human body itself is reliant upon the maintenance of an appropriate balance of elements and minerals. The discipline of medical geology can assist in the elucidation and management of many public health issues, ranging from the effects of exposure to or deficiencies of trace elements and minerals in the diet, to the transportation, modification and concentration of natural compounds in the soil, atmosphere and water sources.

The activity known as *public health* has been subject to a range of interpretations. In fundamental terms, however, its focus is to provide *population-based solutions to collectively-defined health problems*. The emphasis on the incidence, distribution, and control of diseases within a population is often contrasted with the focus of clinical medicine, which is directed towards how illness affects an individual patient.

One widely cited definition is from the *Acheson Report on Public Health* (1988), in which public health is described as:

> The science and art of preventing disease, prolonging life, and promoting health through organised efforts of society.
>
> (Great Britain. Dept. of Health and Social Security. Committee of Inquiry into the Future Development of the Public Health Function. and Great Britain. Dept. of Health and Social Security. 1988)

Another, more extensive definition, was provided by John Last in the *Dictionary of Epidemiology* (1995):

> Public health is one of the efforts organised by society to protect, promote, and restore the people's health. It is the combination of sciences, skills, and beliefs that is directed to the maintenance

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Fig. 2.1 A community exposed to occupational and environmental geogenic material: an iron-ore mining town located in the arid Pilbara region, Western Australia (Picture courtesy of Fiona Maley)

> and improvement of the health of all the people through collective or social actions. The programs, services, and institutions involved emphasize the prevention of disease and the health needs of the population as a whole. Public health activities change with changing technology and social values, but the goals remain the same: to reduce the amount of disease, premature death, and disease-produced discomfort and disability in the population. Public health is thus a social institution, a discipline, and a practice.
>
> (Last and International Epidemiological Association 1995)

There are two core components needed for the operation of a successful public health system: an "*analysis/investigation" function* and *an "action/intervention" function*. The first set of activities includes monitoring and surveillance of communicable (infectious) and non-communicable – often more chronic – diseases. In response to the information gathered from these sources, an intervention – or group of interventions – is then implemented. These may range across a wide spectrum of activities, including health legislation (such as those relating to tobacco control or driving under the influence of alcohol or drugs), regulations to control occupational or environmental hazards, the provision of specific public health services (such as screening programs), or the implementation of health promotion measures (such support of health lifestyles and behaviours) (World Health Organization 1998). The public health measures may be directed towards the entire population or they may, depending on the health issue of interest, target vulnerable and high-risk populations.

This chapter will explore a number of these public health approaches in greater detail, where possible using examples to illustrate how medical geology can and has contributed to the elucidation and mitigation of public health problems.

2.2 Historical Background

Although many of the features of modern public health systems arose in the nineteenth and twentieth centuries, there were a number of precedents in earlier periods. The Classical Romans constructed systems to supply clean water to their cities – including impressive networks of aqueducts, cisterns and domestic pipes – although these were often lined with a malleable metal (*plumbum*, or lead) whose toxic effects were not fully appreciated. The public health implications of fuel use became apparent in the early 1300s, with the banning of coal burning in London because it lead "to the annoyance of the magistrates, citizens, and others there dwelling and to the injury of their bodily health" (Nef 1966). In the expanding cities of late medieval Europe, there were attempts to regulate urban waste and to limit the movements of infected people (such as those with leprosy). The Italian city-states were notable in their achievements, with the foundation of civic hospitals (including specialised plague hospitals), establishment of public Boards of Health (such as the Milan *Sanità*, 1424), and the strict enforcement of quarantine regulations. In the 1600s, the field of medical demography and analysis of population data advanced with the publication of John Graunt's *Natural and Political Observations ... upon the Bills of Mortality* (1662), in which it was noted that more boys were born than girls and that urban mortality exceeds that of rural areas (Porter 1998).

However, it was the Industrial Revolution and subsequent societal shifts in the nineteenth century that created a new series of health challenges. Increasing numbers of people migrated from the countryside to the cities, where many were forced to take on dangerous, arduous work for near-subsistence wages. The population was growing rapidly without a concurrent expansion in new housing, and overcrowding contributed to the relatively fast spread of disease in many urban centres.

One of the leading reformers of this period was Sir Edwin Chadwick (1800–1890), a lawyer from Manchester who took an active part in the modifications to the Poor Law and in factory legislation. Public health became a political issue in 1842 with the publication of Chadwick's *Report on the Sanitary Condition of the Labouring Population of Great Britain* (Chadwick and Great Britain. Poor Law Commissioners. 1842). Chadwick had collated vast quantities of vital statistics, information from town maps, and descriptions of dwellings and problems with living conditions (such as inadequate drainage and foul odours). Chadwick viewed the problems of destitution, slums, smoke, water supply and sewerage as matters for *public action,* as opposed to simply being the responsibility of individuals or local authorities (Porter 1998). Chadwick's advocacy and influence contributed to the first *Public Health Act* in 1848, which established a General Board of Health. This central authority was empowered to set up local boards with the task of ensuring that new homes had proper drainage and that local water supplies were dependable. Furthermore, the first Medical Officer of Health for Great Britain was appointed. By 1872, local boards of health were compelled to employ medical officers of health who were responsible for sanitary inspection and improvement, and isolation and tracing of persons with infections. Other public health legislation, covering factory management, child welfare, care of the elderly and those with physical or mental disabilities, and many other initiatives in social reform were introduced.

In the United States, boards of health were created in the eastern seaboard cities in the 1830s, but they were largely concerned with quarantine regulations. A national awareness of epidemic disease arose from the trauma of the Civil War (1861–1865), in which a large proportion of deaths arose from infections (especially dysentery). Louisiana formed the first state board of health in 1855 and most other states followed by the 1870s. Social conditions deteriorated in the large cities between 1860 and 1890 as a result of increased industrialisation and immigration, leading to a range of social reforms, including those relating to public health. In 1872, the American Public Health Association was formed as a multidisciplinary consortium of engineers, physicians and public-spirited citizens, especially members of the women's movement who spoke of sanitary reform as 'municipal housekeeping' (Rosen 1993).

New discoveries in the field of microbiology also fired a series of new public initiatives and a greater degree of community awareness about infectious disease. Improved methods for water and food sanitation and safety emerged. Rodent and pest control grew in importance. Individual hygiene practices were encouraged. In 1920, Charles Winslow, an American authority on public health and professor at Yale University, emphasised the importance of *"organised community efforts for the sanitation of the environment"*, *"the control of community infections"* and, more broadly, *"the development of the social machinery which will ensure to every individual in the community a standard of living adequate for the maintenance of health"* (Winslow 1920).

Despite these improvements in public health in the early years of the twentieth century, there were a number of unwanted effects of increasing industrialisation, population growth and urbanisation. The environmental and health impacts of widespread mining, metallurgical activities (such as smelting and refining) and fuel extraction (such as coal) also became increasingly apparent (Krech et al. 2004). High levels of pollutants were released into the atmosphere, waterways and soils. The Industrial Revolution was also associated with a growing incidence of occupational diseases, such as lung disorders (examples include coal workers pneumoconiosis, silicosis, and asbestosis), occupational cancers, and poisoning from various toxic compounds (including lead, white phosphorous, mercury, cadmium, arsenic and radioactive agents).

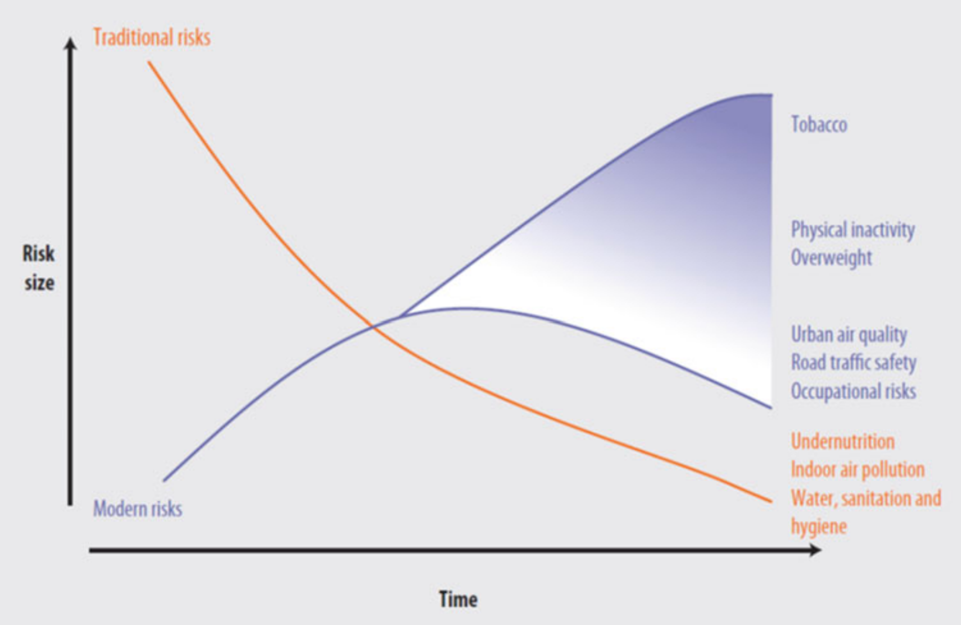

Fig. 2.2 Risk transition in public health. The diagram indicates the magnitude of the shift from "traditional" risks (such as from inadequate nutrition and poor water supply) to "modern" risks over time. The scale of the time variable varies depending on the particular community (Source: World Health Organisation 2009: http://www.who.int/healthinfo/global_burden_disease/global_health_risks/en/index.html)

2.3 Current and Future Trends and Priorities in Public Health

In general terms, industrialised, high-income nations have undergone a significant shift in disease patterns in the past century (Mathers et al. 2009). The increasing average wealth of a nation broadly corresponds to improvements in hygiene and nutrition, substantial declines in the frequency of infectious diseases, and improved population health indicators (such as life expectancy). In many respects, high-income nations have many of the previous "external" or "environmental" causes of disease under control through prevention or management of infectious disease, removal of many water and food contaminants, and improved safety standards and regulations (Fig. 2.2). However, affluence has also been accompanied by increased levels of sedentary behaviour and overnutrition, contributing to such problems as obesity, metabolic disorders and cardiovascular disease. The causes of death in industrialised society primarily relate to chronic diseases – such as cancer, cardiovascular disease, some respiratory diseases – and to a lesser degree, injury and accidents (e.g. in workplaces or from motor vehicle accidents). Many of these current health problems relate – at least partly – to attitudes and behaviours relating to smoking, diet, exercise levels and alcohol intake. As leading researchers have noted with respect to one of the major "lifestyle" diseases, type II diabetes mellitus: "overall, a healthy diet, together with regular physical activity, maintenance of a healthy weight, moderate alcohol consumption, and avoidance of sedentary activities and smoking, could nearly eliminate [this disorder]" (Schulze and Hu 2005).

There remains a significant contrast in health status between those in lower- and higher-income countries. A comparison of causes of death (in millions) for low-, middle- and high-income countries (2004) is provided in Table 2.1. Traditionally, as we noted above, affluence has been linked to those diseases arising from tobacco use, consumption of alcohol and energy-rich foods, and a sedentary lifestyle. In contrast, those living in poverty have usually been perceived as being at risk of inadequate health infrastructure and limited access to care, with the prospect of famine, recurrent infections and a limited life span.

However, this overly simplified description does not capture the current and evolving profile of global health (Lopez and Disease Control Priorities Project 2006). In recent decades, there have been profound changes in many "developing" countries (especially across Asia and Latin America) with accelerating industrialisation and economic development, urbanisation of populations, and globalisation of food systems. Life expectancy is increasing in many parts of Latin America, North Africa, the Middle East and Central and East Asia, although there remain significant variations within and between communities. This rise in average life expectancy primarily relates to a decrease in infant/childhood deaths.

An additional shift has been the "nutrition transition": that is, a shift away from traditional diets to "Westernised" diets (highly processed, high energy, low fibre) and towards lower levels of physical activity. This has led to the co-existence of under- and over-nutrition in many middle-income countries. Rates of cardiovascular disease and diabetes are now dramatically escalating (Yach et al. 2006).

At the same time, major health problems in lower-income countries continue to be associated with poor sanitation,

Table 2.1 Comparison of causes of death (in millions) between low-, middle- and high-income countries (2004)

Disease or injury	Deaths (millions)	Percent of total deaths	Disease or injury	Deaths (millions)	Percent of total deaths
World			***Low-income countries***		
1 Ischaemic heart disease	7.2	12.2	1 Lower respiratory infections	2.9	11.2
2 Cerebrovascular disease	5.7	9.7	2 Ischaemic heart disease	2.5	9.4
3 Lower respiratory infections	4.2	7.1	3 Diarrhoeal diseases	1.8	6.9
4 COPD	3.0	5.1	4 HIV/AIDS	1.5	5.7
5 Diarrhoeal diseases	2.2	3.7	5 Cerebrovascular disease	1.5	5.6
6 HIV/AIDS	2	3.5	6 COPD	0.9	3.6
7 Tuberculosis	1.5	2.5	7 Tuberculosis	0.9	3.5
8 Trachea, bronchus, lung cancers	1.3	2.3	8 Neonatal infections	0.9	3.4
9 Road traffic accidents	1.3	2.2	9 Malaria	0.9	3.3
10 Prematurity and low birth weight	1.2	2	10 Prematurity and low birth weight	0.8	3.2
Middle-income countries			***High-income countries***		
1 Cerebrovascular disease	3.5	14.2	1 Ischaemic heart disease	1.3	16.3
2 Ischaemic heart disease	3.4	13.9	2 Cerebrovascular disease	0.8	9.3
3 COPD	1.8	7.4	3 Trachea, bronchus, lung cancers	0.5	5.9
4 Lower respiratory infections	0.9	3.8	4 Lower respiratory infections	0.3	3.8
5 Trachea, bronchus, lung cancels	0.7	2.9	5 COPD	0.3	3.5
6 Road traffic accidents	0.7	2.8	6 Alzheimer and other dementias	0.3	3.4
7 Hypertensive heart disease	0.6	2.5	7 Colon and rectum cancers	0.3	3.3
8 Stomach cancer	0.5	2.2	8 Diabetes mellitus	0.2	2.8
9 Tuberculosis	0.5	2.2	9 Breast cancer	0.2	2
10 Diabetes mellitus	0.5	2.1	10 Stomach cancer	0.1	1.8

Source: http://www.who.int/healthinfo/global_burden_disease/2004_report_update/en/index.html
COPD chronic obstructive pulmonary disease

inadequate hygiene standards, low vaccination coverage, poor access to health services, and malnutrition. Most preventable deaths in these nations occur in children: globally, around 11 million per year die before the age of 5 years, and it is estimated that half of these could be averted through simple, low-cost solutions (Black et al. 2006). The main causes of premature mortality in lower income nations are infections i.e. respiratory tract infections (such as pneumonia), vaccine-preventable disease (including measles, whooping cough, poliomyelitis, tetanus) and diarrhoeal illnesses, many of which are superimposed on a background of poverty and malnutrition. Malaria and HIV/AIDS are also important contributors to mortality (World Health Organization 2003). These health concerns have prompted a range of responses at the local and international level, including the development of the United Nations Millennium Development Goals (MDGs), which seek to alleviate extreme poverty, hunger, illiteracy and disease (UN Millennium Project et al. 2005; World Health Organization 2005).

It is critical to consider the wider social, economic and political context when addressing public health issues. There is ample historical evidence that public health efforts have been most successful when the socio-cultural context has been changed. For example, the separation of sewage from drinking water is arguably the greatest of all public health achievements, although it remains to be achieved in many societies.

Social deprivation and inequality are strong predictors of health status within and between populations, and of trends over time, and consequently much public health effort is directed towards the alleviation of these imbalances (e.g., the World Health Organisation's *Health for All by the Year 2000* (World Health Organization 1981)). Social inequalities lead to differentials across a range of health measures, including: (i) overall mortality rates and life expectancies; (ii) morbidity and disability from a range of specific conditions (e.g., infectious diseases, cardiovascular diseases, adverse perinatal outcomes, injury and poisoning); (iii) risk behaviours/factors (e.g., smoking, physical inactivity; lipid/cholesterol profiles; higher consumption of refined sugars and fats; less fruit and vegetable intake); (iv) physical environmental factors (e.g., residence in flood-prone regions; proximity to contaminated sites, such as those with elevated lead levels from old housing, leaded fuels, and industry);

(v) utilisation of health services (disadvantaged groups tend to have reduced utilisation of preventive services, such as screening). The patterns and underlying causes of such health disparities have been explored in detail in a number of reports and publications (Berkman and Kawachi 2000; Great Britain Working Group on Inequalities in Health and Great Britain Department of Health and Social Security 1980; Marmot and Feeney 1997; Marmot 2005). However the relationship today between health and average income in developing countries is not a simple correlation. Regions with significant improvements in health despite low per person wealth are Sri Lanka, Costa Rica, Kerala in India and parts of China. Mass education and political commitment to primary care are considered to have played an important part in such improvements (Black et al. 2006).

A related issue in public health is the nature and structure of the health system itself. This encompasses not only the specific health facilities (such as clinics and hospitals), but the entire set of related social structures and processes that impinge on the well-being of the community (Scutchfield and Keck 2009). Attributes of the health system that affect health status and the success of disease control include: (i) overall allocation of resources at the governmental level, such as how much of the national budget is to be spent on health as opposed to other areas (such as defence); (ii) the range and effectiveness of preventive, treatment, rehabilitative and continuing care programs available; (iii) access to services (e.g. universality of health care; systems of pricing health services); (iv) the provision of special services to disadvantaged groups.

In 1981, the World Health Assembly endorsed a resolution that health was to be one of the major social goals of government, thereby initiating the "*Health for All by the Year 2000*" (HFA2000) movement (World Health Organization 1981). In this period, health policy shifted progressively towards emphasising *community-based interventions* as the main vehicle for improving health. This has been accompanied by a general shift away from an overly "medicalised" model of health care. This transition was taken further by the *Ottawa Charter* (1986), which advanced the view that it is *people themselves* that hold power in health matters, not just institutions, officials, professionals or those who develop and control technology (Green and Kreuter 1990; Green and Tones 1999). The Charter stressed the importance of *health promotion*, defined as follows:

> Health promotion is the process of enabling people to increase control over, and to improve, their health... Health is a positive concept emphasizing social and personal resources, as well as physical capacities. Therefore, health promotion is not just the responsibility of the health sector, but goes beyond healthy lifestyles to well-being.
>
> *Ottawa Charter* (1986) (World Health Organization. Division of Health Promotion. 1986)

A number of key areas of activity were identified to achieve the health promotion model. These include the *creation of supportive environments*, with provision of living and working conditions that are safe, stimulating, satisfying, enjoyable and conducive to health-enhancing behaviours. This emphasises the need to identify and manage environmental barriers that might prohibit or inhibit optimal health. Another element of promoting health is through *strengthening of community actions*, with an emphasis on using and supporting community resources to promote health. This approach encourages community "ownership" of health and empowerment, in which individuals act collectively to manage the determinants of their health and the quality of life in their community.

2.4 Measuring Health and Disease in Populations

Health and health status is a complex and abstract concept: there is no single satisfactory definition which encompasses all aspects of health. Traditionally, health has been viewed as the absence of disease. However, the World Health Organization defined health much more broadly as "*a state of physical, emotional and social well-being, and not merely the absence of disease or infirmity.*" Although there has been considerable debate about the merits of this definition, it has provided a focus for the measurement of a broad range of indicators of health beyond just the presence or absence of some clinical or pathological entity.

In attempting to capture a population's overall "state of health," there is a wide array of measures from which to choose. However, most of the commonly used measures have a shared goal: to meaningfully quantify and summarise some dimension of health or disease in a population. An example is the *mortality rate* (or *death rate).* These take different forms: the *crude* mortality rate is the number of deaths in an entire population over a set period (usually a year), expressed per unit of population at risk of dying, whereas *specific* mortality rates are the number of deaths occurring within a subgroup of the population, such as by gender or across particular age strata or ethnic groups. A common measure used for international comparisons is the *infant mortality rate* (IMR): the ratio of the number of deaths of children under 1 year of age (in a given year) divided by the number of live births (in that year).

A related population-based measure is *life expectancy*: the average number of years yet to be lived for individuals at a specified age (commonly taken from birth). It is based on a set of age-specific death rates, and usually draws on the mortality conditions prevailing at the time of the estimate. In low-income countries with high infant mortality, most of the gains in life expectancy occur by improving the likelihood of survival of infants. In contrast, for high-income countries with low infant mortality, most of the gains in life expectancy occur in the oldest members of the population.

However, measures such as mortality rates and life expectancy only capture part of a community's experience of health and disease. For example, mental illness, visual loss and osteoarthritis are all major sources of ill-health in the population, but the extent of such conditions is not reliably captured by examining death rates. Examples from the field of medical geology include the iodine deficiency disorders (IDDs), which are estimated to affect hundreds of millions of people worldwide. A considerable community burden arises from serious neurological deficits (including cretinism and hearing impairments) arising from inadequate iodine during foetal and early childhood development (De Benoist et al. 2004; Mason et al. 2001). However, IDDs in children and adults are not commonly a direct cause of death, and therefore will not usually be detected solely by examining mortality records.

Other measures are required to capture the frequency of a condition or disease in a population, also known as *morbidity*. One of the most important measures of disease frequency is the *incidence*. Incidence reflects the frequency of *new* health- or disease- related events (such as the first onset of a particular disease). These may be expressed as rates, such as new cases per person-year, per person-month, or per person-day. These values may be converted to a rate per 1,000 or 100,000 person-years (for example, cancers are often reported in terms of an incidence rate of *X* cases "per 100,000 person-years".) *Prevalence* is another common measure of morbidity. This encompasses the frequency of *existing* (whether new or pre-existing) *health- or disease-related events*. In other words, prevalence focuses on *disease status,* or the *current "burden of disease"*, in a community, as opposed to the number of new events (which is captured using incidence). Common sources of morbidity data include: disease registries (e.g. for cancers); notification systems for infectious diseases, industrial diseases and accidents, discharge information from hospitals and registers in general practice (family medicine clinics).

In terms of assessing the frequency of events, morbidity differs from mortality in some crucial respects. Death is a well-documented and final state, and is relatively easily enumerated. When counting and summarising other (non-fatal) "disease states" across the community, however, there are a far wider range of measures available. At the biological level, morbidity may for example be assessed using *biochemical markers* (e.g. blood glucose), *physiological markers* (e.g. blood pressure), and *pathological markers* (e.g. tumour size; evidence of dental or skeletal fluorosis). Alternatively, functional measures of morbidity reflect how a disease or condition results in *impairment* (reduction in physical or mental capacities at an organ or bodily system level)*, disability* (restriction in a person's ability to perform a particular task or function, such as walking) and *handicap* (limitations in a person's ability to fulfil a normal social role, such as their usual job).

Morbidity may also be assessed using *self-reported measures*, which are used to assess factors associated with quality of life, such as "wellness," psychological and emotional wellbeing, or social functioning. These aspects of poor health and disability are of great importance to patients but are often difficult to measure.

'Composite' measures of health status combine the aspects of those described above, such as life expectancy and morbidity indicators. One example is the *Disability Adjusted Life Year, or DALY*. This metric takes into account both the fatal and non-fatal outcomes of disease. One DALY can be thought of as one lost year of "healthy" life due to death, disease or disability. It quantifies the health burden in terms of years of life lost (due to premature death) and years "lost" to disability, with different "weights" assigned to medical conditions depending on their severity. One of the most important functions of DALYs is to assess the national (or global) burdens of disease and injury associated with certain diseases or groups of diseases. In higher-income countries, significant DALYs are associated with cardiovascular diseases, mental illness, dementia, cancers, diabetes and injury (e.g. road traffic accidents). In middle- and low-income countries, cardiovascular diseases, and mental illnesses are also important, but infectious diseases and perinatal conditions also account for a significant burden (Lopez and Disease Control Priorities Project 2006). The use of DALYs can be extended to assess the global burden of disease and injury associated with particular risk factors, such as DALYs "lost" from malnutrition (including iron and/or iodine deficiencies), unsafe water supplies (including those containing excess fluoride or arsenic), tobacco and alcohol use.

In general, the uses of these various sources of health data are diverse. Information on the frequency of diseases causing death and disability provide a general framework for health policy. Morbidity statistics are of particular relevance to health services planning. Statistics on utilisation patterns and the diseases and illnesses presenting to hospitals and other health care institutions are essential to a rational policy for the organisation of health care.

2.5 Assessing Risk in the Community

The term "risk" has multiple interpretations, and is used in different contexts in the field of public health. A *risk factor*, for example, denotes a factor or characteristic associated with (but not necessarily always the direct cause of) a

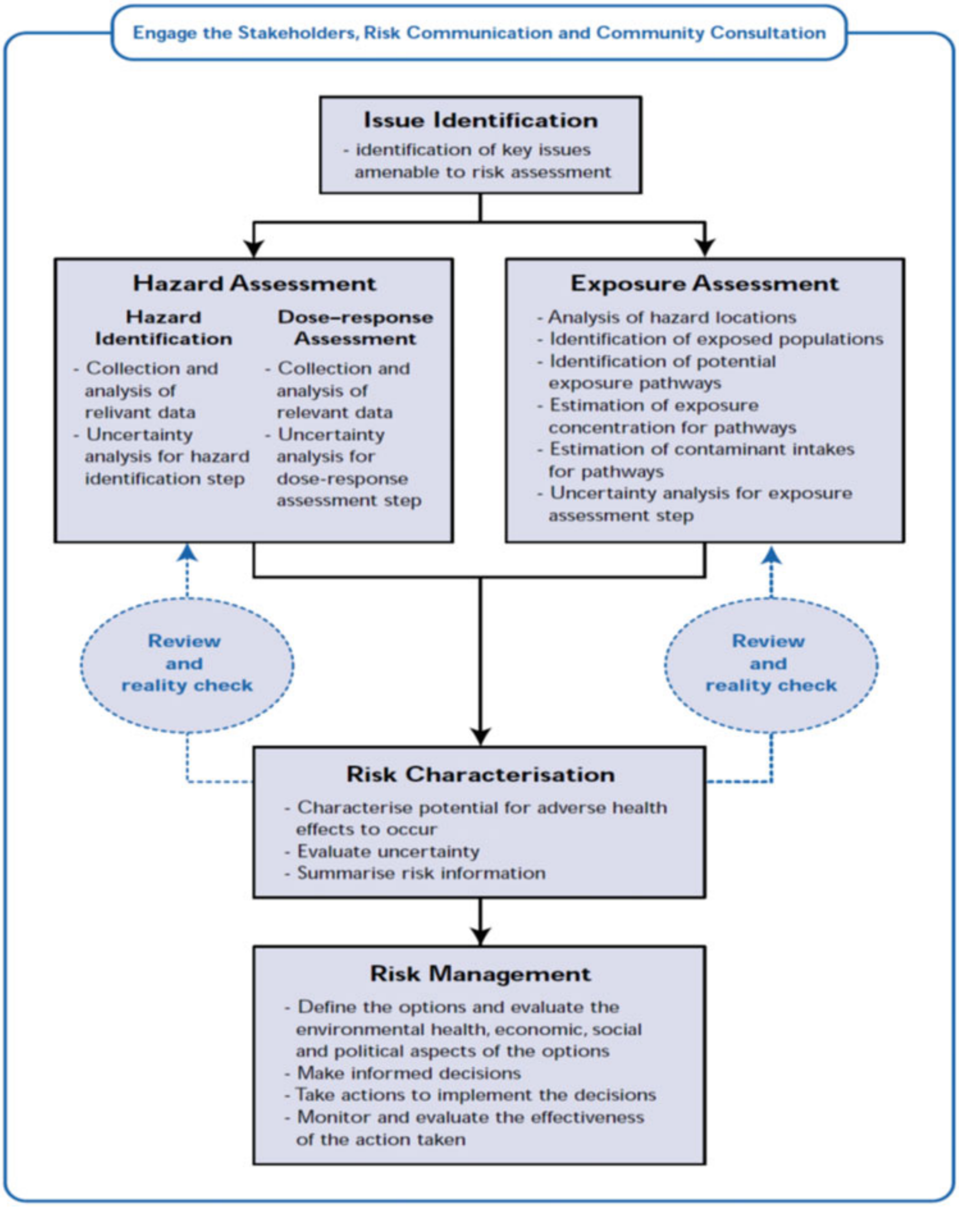

Fig. 2.3 Stages of risk assessment for environmental hazards (from Environmental health risk assessment: guidelines for assessing human health risks from environmental hazards, used by permission of the Australian Government) (Source: Department of Health and Ageing, Canberra, Australia/ enHealth Council 2002: http://www.nphp.gov.au/enhealth/council/pubs/pdf/envhazards.pdf)

particular disease or outcome. A risk factor can be an aspect of behaviour or lifestyle, an environmental exposure, or an inborn or inherited characteristic, that is associated with an increased occurrence of disease or other health-related event or condition.

Another usage of the term “risk” is within the framework of a *risk assessment*. In general, this process involves estimating the potential impact of chemical, biological or physical agents on a specified human population over a given time. In a medical geology setting, such assessments can be considered in terms of: (i) *defining exposure pathways*: such as the nature of the geological hazard, including its physicochemical properties and bioavailability; whether there are multiple and/or interacting hazards (e.g. from various sources); the routes of exposure; and projected patterns of exposure in at-risk populations; coupled with: (ii) *defining the progression to health end-points:* that is, the probability that the geological processes or agents are likely to produce any adverse health effects. This may involve defining the relationship between toxicant “dose” and occurrence of a particular disease, and calculation of the potential rates of disease in the given population.

This process of evaluation has been separated into a number of discrete stages (Brownson and Petitti 1998; National Research Council (U.S.). Committee on the Institutional Means for Assessment of Risks to Public Health 1983). These are summarised in Fig. 2.3 (enHealth Council and Australian Department of Health and Ageing 2002).

The first component of the risk assessment is **Issue identification**. This involves identifying and confirming a role of the risk assessment approach for a particular issue: that is, Why is this issue of particular concern? Is the issue urgent? How do all the stakeholders (often including the community) perceive the issue? At this early stage, it is essential to consider whether the issue is amendable to the risk assessment approach and to determine the social context (for many environmental issues, there may be a high level of anger, anxiety, and impatience).

Evaluation of risk from complex industrial processes or contaminated sites is often a challenging task because of the diversity of compounds produced and multiplicity of potential exposure contexts and health impacts. In mine tailings, for example, a mixture of pollutants may be present, including: trace elements such as arsenic, mercury, lead, and cadmium; radioactive materials; acid-producing sulphide compounds; fine-grained minerals such as asbestos and quartz; hydrocarbons, often introduced by mining and processing equipment; as well as additives such as cyanide (including leaching agents, sodium cyanide and hydrogen cyanide) (Nriagu 2011).

The next stage is **Hazard assessment**, which – as applied to a medical geology context – often involves investigating a hazardous process or the inherent properties of hazardous agents. This process of assessment requires two major activities: (i) *Hazard identification: Are the agents of concern presumed or known to cause adverse health effects?* The disciplines of toxicology (including animal or *in vitro* studies) and epidemiology (studies of human populations) are used to help address this question. For hazardous chemicals, it is often necessary to collect and compare relevant data on physical state, volatility and mobility as well as potential for degradation, bioaccumulation and toxicity; (ii) *Dose-response assessment: What is the relationship between the dose and occurrence of the adverse health effects? At what dose does this health effect occur?* Estimations of human health risks from exposure to specific chemicals are generally based on extrapolations of the results of toxicological experiments on animals. These extrapolations provide standard human "dose-response" relationships for the chemicals. The validity of the data and the weight-of-evidence of various toxicity data must be assessed.

For example, the International Agency for Research on Cancer (IARC) grades hazards according to whether they are likely to be carcinogenic. One common contaminant, arsenic, is classed as a Group 1 carcinogen based on evidence of its association with a spectrum of cancers (including those of the skin and liver, lung, kidney, and bladder) arising in human populations exposed to this contaminant (such as smelter workers, arsenical pesticide workers, patients treated with arsenic-containing medicinals, and communities who have ingested arsenic in drinking water across many geographical regions (Tchounwou et al. 2003)). However, arsenic is a widely distributed metalloid and occurs in different oxidation states and forms, including elemental arsenic, arsenides, sulphides, oxides, arsenates and arsenites (Centeno et al. 2006; Tchounwou et al. 2004). Therefore, *speciation* of arsenic (and many other compounds) is critical for accurate toxicological evaluation. The particular chemical form (i.e. oxidation/valency states) and physical attributes (morphological state) of the element often determine its toxicity, mobility of an element in the environment, and bioavailability (Refer to Chaps. 27 and 12)

The next component of the risk assessment process is **Exposure assessment,** which seeks to define the exposure pathways that are currently experienced or anticipated under different conditions: that is, *Under what circumstances or conditions could people be exposed to the hazard? What forms of assessment or estimation will be used to determine whether exposure had occurred?* This requires assessment of the following parameters: the frequency, extent, and duration of the exposure; the locations in which the exposure is likely to occur; the exposed populations; the pathways of exposure and actual or predicted intake of contaminants. Depending on the agent and exposure context, intake usually occurs through ingestion (such as incidental ingestion of contaminated soil or dust, or via contaminated food or drinking water), inhalation, or dermal absorption. It must be noted, however, that compounds (such as metals) detected in the environment are not necessarily biologically available to humans because of large particle size, low solubility, limited release from soil, or entrainment in surrounding rocks and soils. Exposure can be estimated *directly* (such as with biological testing or personal monitoring of each individual, including urine, blood, hair and nail samples) and/or *indirectly* through environmental monitoring, questionnaires and diaries.

Risk characterisation [also called **risk estimation**] integrates the preceding analyses of hazard and exposure measurements in order to decide: *What is the estimated probability that adverse outcomes will occur in this particular population at the specific level of exposure?* This assessment on the likelihood of harm is then used to guide the process of decision-making (Stern et al. 1996).

Throughout the risk assessment process, it is important to conduct ongoing **evaluation of limitations and uncertainties.** There are always likely to be elements of uncertainty in the analyses and these need to be explicitly acknowledged. These include: gaps in information about the profile of the hazards at a particular site; inadequate exposure information, including problems defining the population affected or the geographical area involved; limits in the availability and consistency of toxicology data, including extrapolations of findings (e.g. from animal studies) to human populations; limitations in the use of point estimates in the present day when trying to infer past exposures over a long duration. For many toxic agents, there may be no specific models to define the relationship between contaminant levels or durations of exposure and the probability of disease outcomes.

The conclusions from the risk assessment process are then used to inform the final stage: **Risk management**. This involves evaluating possible actions and alternatives to minimise risk, taking into account all the relevant factors: the risk assessment, as well as the practicality (cost and technological constraints), social and political implications of the available options. A "zero risk" option is usually not achievable, given that almost any action potentially entails some degree of risk. The strategies are then implemented and monitored to ensure that they have been effective. Risk management also involves deciding upon the process and form of engagement and communication with relevant stakeholders, including the community. This process is often influenced by the degree of outrage experienced by public, the intensity of media attention, and attribution of blame (e.g. whether the problem was caused by a natural event or by human error) (Covello et al. 1989).

2.6 Monitoring and Surveillance of Disease

Many communities and countries have a formal set of arrangements to prevent, monitor and respond to communicable and non-communicable diseases. These "surveillance systems" aim to provide *"a continuous and systematic process of collection, analysis, interpretation, and dissemination of descriptive information for monitoring health problems*" (Rothman et al. 2008). Usually the surveillance systems are operated by public health officials to assist in disease prevention and to guide control.

In *active* surveillance, the health agency actively initiates information gathering, such as by regular calls or visits to doctors or hospitals. In contrast, for *passive* surveillance, the health agency does not actively contact reporters – it leaves the contact to others (such as treating doctors). Often both active and passive options exist in the same system. For example, the surveillance organisation may actively contact large representative hospitals while leaving smaller centres to passively participate.

In the process of *notifiable disease reporting*, health workers are (often legally) required to contact a central public health agency when a particular disease is identified. Examples include infectious diseases with serious health implications, such as whooping cough, cholera or rabies. The time requirements vary: some diseases require rapid notification; with others, there is less urgency. Other systems for obtaining health data include: *laboratory-based surveillance,* in which summaries (e.g. of microbiological samples) are provided by a laboratory; *registries*, which are designed to capture all occurrences of a disease or group of diseases (such as cancers) in a specified area; and *surveys*, which involves direct contact with a community, or a sample population, to define an outcome of interest, such as the presence of disease, levels of risk behaviour, or use of health services (Silva and International Agency for Research on Cancer 1999). Diagnostic tests form an important basis for identifying those with the disease or outcome of interest. It is imperative to consider the accuracy and availability of the tests, how they are used, and whether they are being reliably interpreted.

The populations to which surveillance is applied may be defined in narrow terms (such as a hospital) or in broad terms (e.g. the global population, as conducted by the World Health Organisation in tracking the emergence of new influenza strains). Surveillance systems need to maximise confidentiality: it is an ethical requirement and is required to engender community trust in the system. Usually security measures are put in place to ensure that no violations of privacy can occur.

Surveillance systems have different objectives. They may be to provide rapid feedback (e.g. in infectious disease outbreaks) or may be used for longer term health care planning or monitoring of prevention programs. For example, surveillance data can be used to identify whether changes in disease incidence are occurring, such as by comparing them to historical records. Declining trends can follow the pattern of disease or the effectiveness of control measures (e.g. infection incidence after the introduction of an immunisation campaign).

Examples of surveillance systems with particular applications to medical geology include those designed to assess the health consequences of lead exposure. The presence of lead in the environment was, and in many locations remains, a major environmental hazard, with sources including leaded gasoline, lead-based paint, other household items containing lead (e.g. ceramics, toys), and contamination from mining, smelting and other industrial processes (e.g. battery manufacture). The presence of lead and its capacity for ingestion by children – such as in paint, dust or contaminated soils – has major implications for health, particularly in relation to neurodevelopmental effects. Elevated lead has been linked to behavioural disturbances, delayed learning, and diminished intellectual capacity in children. Other effects of lead exposure in children and adults include renal damage, anaemia and a range of other toxic effects on the reproductive, neurological and cardiovascular systems.

In the United States, population-based programs have been established to evaluate young children for signs of lead poisoning, primarily through blood tests and clinical evaluations (United States. Dept. of Health and Human Services. Committee to Coordinate Environmental Health and Related Programs. Subcommittee on Risk Management and Centers for Disease Control (U.S.) 1991). This public health issue has been addressed through various forms of surveillance, including: (i) at the State level: reviews of blood lead level (BLL) analyses from laboratories, which may also incorporate information gathered directly by public health officials or clinicians (e.g. evidence of lead toxicity – such as developmental and behavioural disorders – and/or risk factors for lead exposure in screened children); (ii) at a national level: the Centres for Disease Control's National Center for Environmental Health is responsible for developing and maintaining the national surveillance system for childhood lead levels. In practical terms, this task involves centralising the data (mainly laboratory blood lead tests, with personal details removed to ensure confidentiality) from participating agencies across the United States. This aggregated information is then collated and analysed to identify those regions and communities at highest risk, to target interventions, and to track the progress of programs that aim to reduce lead exposure (Centers for Disease Control and Prevention CDC's National Surveillance Data (1997–2008)).

2.7 Disease Prevention and Control

Preventive health care is a term used to describe a range of both *technical* and *educative strategies* applied by doctors, nurses, allied health professionals and public health workers in community and clinical settings. These interventions are designed to prevent the onset of disease or to slow or stop the progress of illness, and may be applied at different stages in the natural history of disease.

These strategies are commonly categorised in terms of *primary, secondary* and *tertiary prevention*. *Primary prevention* seeks to prevent the occurrence of disease altogether (that is, it aims to reduce disease *incidence*). It often focuses on strategies to control hazards (e.g. infectious agents; chemicals) and to modify risk factors in the population through health promotion and health education (such as by reducing smoking or encouraging greater participation in aerobic exercise).

With respect to minimising exposure to hazardous chemicals, primary prevention usually involves a combination of education and legislation. For example, exposure to asbestos and natural asbestiform compounds has major implications for health, including asbestosis (diffuse fibrosis of the lung), pleural lesions and various cancers. Contact with asbestos and asbestiform compounds may be controlled through the following strategies (United States Environmental Protection Agency 2012):

- Government legislation to prevent extraction and use of asbestos in building or for other industrial purposes
- Public and worker education
- Establishment of exposure limits (e.g. maximum allowable concentrations)
- Strict controls on removal and replacement of existing asbestos materials (e.g. insulation)
- Use of protective equipment and warning signs

Many other geological materials are also monitored and regulated in order to limit the degree of public and occupational exposure. These include metals and metalloids (such as arsenic, lead, mercury, cadmium, chromium, and beryllium), silica dusts, and radionuclides.

Secondary prevention is designed to intervene early in the course of a disease to halt or slow its progress, and thereby stop or reduce its clinical manifestations. Secondary prevention of both communicable and non-communicable diseases is closely related to the concept of disease *screening*, which is the identification of preclinical disease (usually by a relatively simple test). Screening is the evaluation of people who are apparently healthy (that is, without clinically overt symptoms) "to detect unrecognized disease [or its early biological manifestations] in order that measures can be taken that will prevent or delay the development of disease or improve the prognosis" (Last and International Epidemiological Association 1995). In practice, secondary prevention involves the *interaction of community health measures* (mass screening campaigns, central registers e.g. for cytology, mammography) and *clinical medicine*, such as through family doctors who provide clinical screening services (such as cervical smears).

In general, the screening procedure is not *in itself* designed to simply diagnose the end-stage illness. It is assumed that screening will detect a disease at an earlier stage than would have occurred otherwise, and will thereby offer the potential for improved prognosis (a greater chance of survival). However, it is also important to emphasise that screening alone (that is, simply achieving early detection) is not enough to constitute prevention. It is the combination of screening and the subsequent application of an effective early intervention that comprises secondary prevention.

Tertiary prevention differs from the primary and secondary approaches in that it is applied after the diagnosis of the disease. It aims to intervene later in the course of disease so as to reduce the number and impact of complications which add to the patient's disability and suffering. Tertiary prevention may be difficult to distinguish from treatment because it forms an integral part of the clinical care plan for patients with established disease. The basis for the distinction is that a *preventive intervention* is one that is applied before a potential problem occurs, such as debilitating complications (e.g. eye or kidney damage from diabetes mellitus), whereas *treatment* is applied to alleviate a problem that has actually occurred. The different stages of prevention are summarised in Fig. 2.4a, with an example provided using exposure to asbestos-induced cancer (Fig. 2.4b) (Das et al. 2007; Tiitola et al. 2002; Wagner 1997).

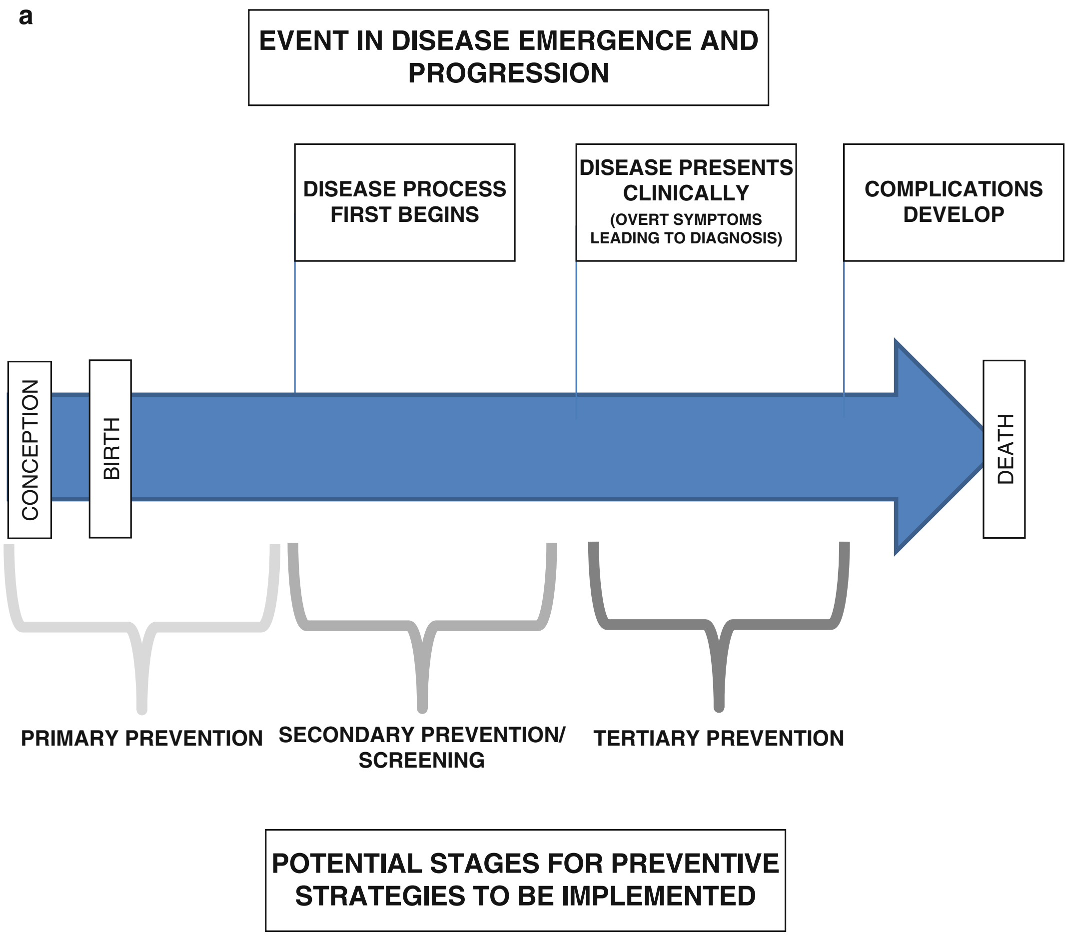

Fig. 2.4 (**a**) Overview of preventive strategies in relation to disease progression. (**b**) Illustration of preventive strategies as applied to an asbestos-induced cancer

In the field of preventive medicine, a distinction is often possible between two competing strategies for prevention: those oriented towards the *population* versus those oriented towards *high-risk groups or individuals*. In other words, there is debate over whether such initiatives should seek to address the needs of "sick individuals" or "sick populations" (Rose 1985)? In population strategies, efforts at prevention are directed *en masse* at an entire community (or significant portions of the community). Examples include the provision of general nutritional advice to consume more fruit and vegetables; screening of biochemical disorders at birth; health checks in women, men or older age groups. In contrast, a high risk strategy targets specific diseases or predisposing conditions in individuals known to be at higher risk of developing the condition. For example, lung function tests and imaging may be used to detect lung disease (such as pneumoconioses) in those who have worked in the industries with high levels of mineral dusts.

The distinction between population and high risk strategies is illustrated by considering possible public health strategies for the control of elevated blood lipids ("high cholesterol") (Rose 1993). A general population approach would tend to use regulatory, educative and structural strategies across the community (such as through advice on nutrition and exercise through the media) to reduce the overall levels of blood lipids in the entire population. In comparison, a "high-risk" approach might involve screening for high levels of blood lipids (such as through the individual's family doctor) followed by specific dietary or medication regimes in those identified as being at high-risk. Depending upon the nature of the risk factor and the disease, a combination of both population-based and high-risk strategies may be implemented.

In practical terms, a large number of people exposed to a small degree of risk (e.g. moderately elevated cholesterol or moderately excessive bodyweight) may generate many more cases than a small number of people with high risk (Rose 1993). Therefore it may be necessary to focus on modifying behaviour in the large mass of people with slightly elevated risk in order to have a major impact on the overall rate of

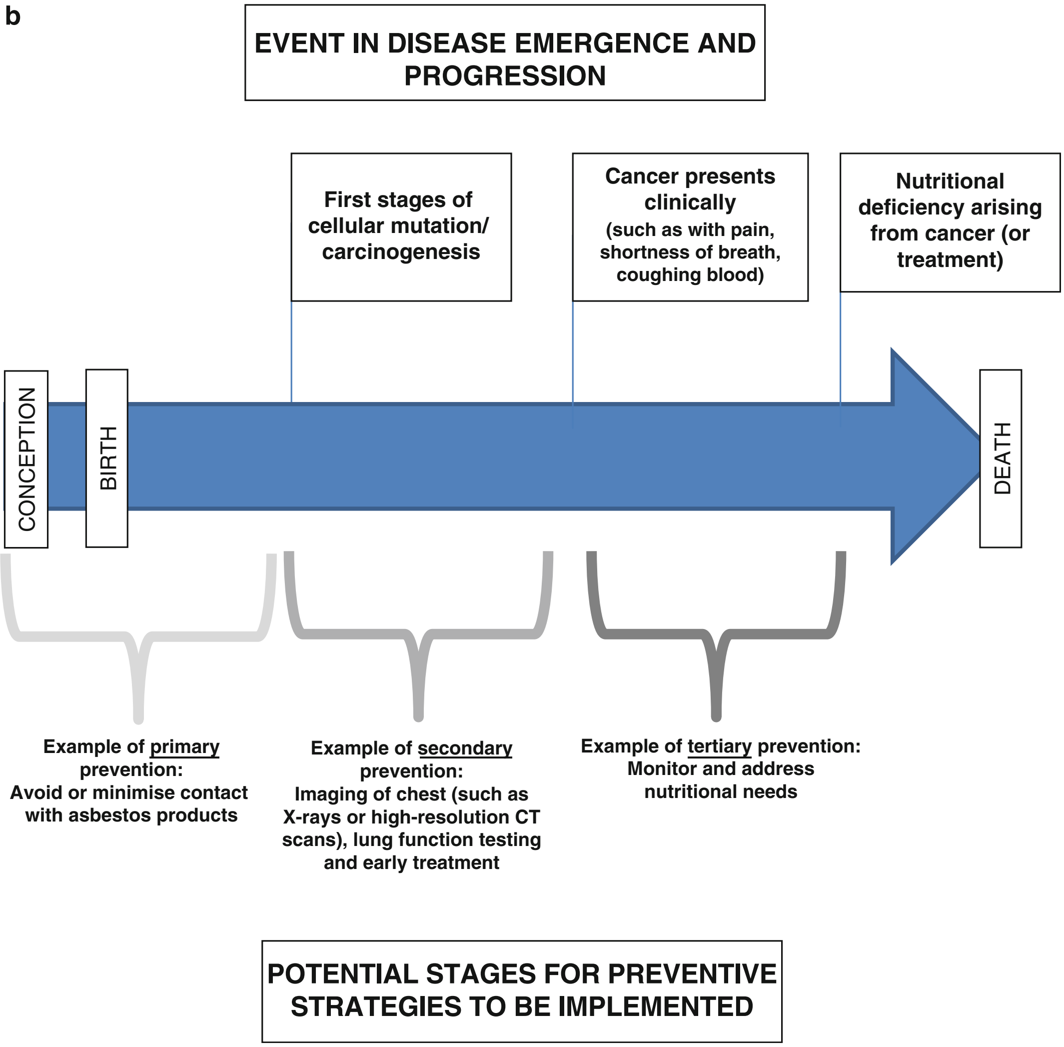

Fig. 2.4 (continued)

disease. In general, any preventive strategy should seek to provide the greatest benefit to the largest number of people, while also attempting to minimise the chance of causing inadvertent harm to the same population.

2.8 Research Methods in Public Health

Research into public health issues often employs the approaches and techniques of *epidemiology*. Epidemiology is broadly defined as the study of disease patterns in populations. Epidemiological analyses often seek to discover the causes, determinants or risk factors of a disease, usually in order to make prevention possible. The factors that may impact on disease include: hazardous agents such as micro-organisms or toxic chemicals, trace elements and minerals; lifestyle factors; and genetic influences. The term *environmental epidemiology* is often used to apply factors in the environment that impact on disease, ranging from pollutants to infectious agents. Many of the principles of environmental epidemiology also have implications for studies used in the field of medical geology, and are described in Chap. 23.

There are three underlying questions common to all epidemiological studies. The first question is: *Who is to be sampled?* The study population must contain a proportion of people who either have the disease of interest or are potentially at risk of developing the disease, and should be representative of any broader populations to which the study results will be applied. The study population must be of sufficient size – and, by implication, a sufficient number of the participants must experience the exposure and disease events of interest – to achieve the required statistical power in the analysis. For example, an analysis of the relationship between inhalation of beryllium dust and lung cancer that drew all its participants from the general population would be inefficient, because high levels of exposure to this compound in the community is relatively uncommon. Other practical issues that must be considered include the likely degree of cooperation from the study population, accessibility of the participants for enrolment, maintenance of confidentiality of the data, and the overall cost of recruitment, evaluation and follow-up of the participants.

The next question is: *How is data collection to proceed?* This involves considering the optimal approach to capturing information on the *risk factor or exposure of interest* and the *subsequent disease events*. Many methods may be used to estimate risk factors and exposure, including the use of interviews, questionnaires or diaries for each individual (Nieuwenhuijsen 2003; White et al. 2008). In some situations, physical or chemical measurements may be used at the point of contact, such as with personal monitoring (two well-known examples include dust monitors used by mining personnel and personal dosimeters used to record ionising radiation exposure). Bioindicators or biomarkers are measurements from body tissue, fluid or excretion products to obtain data on past exposure to chemicals or other agents. Exposure may also be inferred through use of physical, chemical and biological measurements of the environment, including soil, air, food, water and indicator organisms. For disease events, the process of ascertainment may include self-reports of illness, medical records, laboratory results, or the study itself may involve testing procedures in the protocol (Silva and International Agency for Research on Cancer 1999).

Lastly, *What sort of analysis and evaluation is planned*? This involves a thorough interrogation of the data: Were the sampling procedures conducted successfully? How strong is the evidence of an association between the exposure and the disease? How much of the relationship between exposure and disease might be influenced by random variation, bias (systematic distortion of results) or confounding (mixing of effects)? How generalisable are our data to other populations?

Epidemiological results are often presented in terms of *measures of effect*. In general, these provide an estimate of the magnitude of association between the *risk factor or exposure* and *the disease* (or outcome of interest). A commonly used measure of effect is the *relative risk (RR)*, which estimates how many times more likely it is for "exposed" persons to develop the disease relative to "non-exposed" persons. An example of how these relative measures are applied is provided by Baris and Grandjean (2006) in their prospective study of mesothelioma mortality in Turkish villages exposed to fibrous zeolite. (In certain villages on the Anatolian plateau in Turkey, inhabitants are exposed to erionite, a form of fibrous zeolite, which is present in the volcanic tuffs that are used as building stone. Mesothelioma is an aggressive form of cancer linked to exposure to certain fibrous minerals.) In this study, the residents from a selection of villages in the area were followed up for the period 1979–2003, and the mortality rates from mesothelioma were calculated. For one of the analyses, adults from villages with high levels of erionite exposure were compared with a non-exposed "general population": in this case, the population of another country (Denmark) was used as the referent. The authors reported that the mortality rate from pleural mesothelioma (which affect the membranous linings the lungs and chest cavity) of highest-risk villages *relative to* the general population was 485 (a measure called the *standardised mortality ratio* for pleural mesothelioma). In other words, the "exposed" population (that is, residents from the high-risk villages) were 485 times more likely to develop pleural mesotheliomas than a "non-exposed" ("general") population.

Epidemiological studies are often classified into different groups, depending upon their purpose and design. These include *descriptive studies*, *analytic studies*, and *intervention/experimental studies*. A brief outline only is provided here, and readers seeking more detail are encouraged to refer to Chap. 23 or a general textbook on epidemiological principles (such as (Farmer and Lawrenson 2004; Gordis 2009; Rothman et al. 2008; Szklo and Nieto 2007)).

Descriptive studies often focus on the "time, place and person" component of epidemiology. In other words, such studies seek to determine: *Who* is at particular risk of this disease? *When* did they get the disease? *Where* are they located?

The "person" component of the analysis identifies the characteristics of the group at risk of the disease, such as their age, gender, ethnicity, occupation, personal habits and presence of co-existing disease. The "place" component determines the spatial dimension of the disease events. Diseases may vary with the biological environment (e.g. local ecology may influence the presence of disease vectors, such as mosquitoes carrying malaria), the physical environment (e.g. climate; geology) and the sociocultural environment (e.g. sanitation and hygiene practices; cultural practices; nature of social interactions). The importance of place and of mapping diseases has been part of epidemiology since the discipline formally began: John Snow famously mapped cholera cases around the Broad Street water pump in London in 1854, thereby helping to confirm that the disease was water-borne (and not spread by miasmatic vapours, as had been widely assumed). The spatial patterns of disease can often provide supporting evidence for the underlying disease process, such as relating cases of thyroid cancer to the Chernobyl nuclear accident or the increased risk of kidney damage in areas with cadmium contamination in Japan.

The "time" component of descriptive studies defines how the frequency of the disease varies over a defined interval (or may seek to determine whether the disease frequency is different now than in the past). *Time series* *studies* refer to analyses that follow the rates of disease in a given community or region through time. Time patterns in disease may be: *short-term*: temporary aberrations in the incidence of disease, such as outbreaks of gastroenteritis; *periodic/cyclical*: diseases with a recurring temporal pattern, such as the seasonal fluctuations in respiratory diseases, which are often more common in the winter months, or; *long-term/secular:* changes in the incidence of disease over a number of years or decades, such as the rise in HIV/AIDS incidence since the 1980s.

Different terms are used to capture variations in the disease pattern. An *epidemic* refers to a general rise in case numbers above the background rate of the disease. An *outbreak* usually refers to a localised epidemic, and is often applied to infectious diseases. Although a *cluster* also refers to a close grouping of disease (or related events) in space and/or time, it is usually applied to uncommon or specific diseases, such as birth defects or cancer.

An example of how this descriptive approach may be applied is provided by the outbreak of coccidioidomycosis in California in 1994 (Pappagianis et al. 1994). This infectious disease usually results from inhalation of spores of the dimorphic fungus *Coccidioides immitis*, which grows in topsoil. In their report, the study authors define the "time, place, person" components as follows: "[f]rom January 24 through March 15, 1994, 170 persons with laboratory evidence of acute coccidioidomycosis were identified in Ventura County, California." This number "substantially" exceeded the usual number of coccidioidomycosis cases seen in Ventura County. To account for this change in incidence, the authors noted that the "increase in cases follows the January 17 earthquake centered in Northridge (in adjacent Los Angeles County), which may have exposed Ventura County residents to increased levels of airborne dust" (Pappagianis et al. 1994). The temporal and geographical pattern were supported by subsequent environmental data indicating that significant volumes of dust been generated by landslides in the wake of the earthquake and aftershocks, and that this dust had been dispersed into nearby valleys by northeast winds (Schneider et al. 1997).

Another group of epidemiological studies are termed *analytic*. Traditionally, these address specific hypotheses using more formalised designs than the descriptive studies, and incorporate a well-defined comparison ("control") group. For example, in *case-control studies*, the population is first defined with reference to the presence or absence of disease (such as lung cancer). The individuals with the disease, known as the "cases", are compared to a non-diseased group (known as the "controls") with respect to some exposure history (such as their past employment in the asbestos industry). In contrast, for *cohort studies*, a study population is first defined with reference to their degree of exposure or presence of the risk factor (such as the number of years they have been employed in the asbestos industry). This population is "disease-free" at the start of the study period. The participants (known collectively as a "cohort") are then followed over time to determine who experiences the disease (such as lung cancer) and who does not.

This analytical approach is demonstrated in the prospective study of arsenic exposure from drinking water and skin lesions (skin thickening or changes in pigmentation) in Bangladesh by Argos et al. (2011). (The skin lesions are often precursors to later skin cancers.) This cohort study involved identifying a group of around 10,000 individuals who were free of skin lesions at the start of the study. The exposure variable was defined as differential use of wells in the study area as a source of drinking water. There were a total of 5,966 wells, encompassing a range of arsenic levels from the detection limit (0.1 μg/L) to >200 μg/L. The study participants were followed for the years 2000–2009 (inclusive) and assessed clinically to determine who developed skin lesions. The authors reported that for every quintile increase in the concentration of arsenic measured in the well water, there was a 31 % increase in the risk of developing skin lesions.

In environmental epidemiology, one of the main challenges in conducting analytic studies relates to the reliable estimation of exposure. Although a range of environmental sampling techniques are available, it may be difficult to infer personal exposure based on such measurements. In practical terms, samples are often collected over short periods of time that may not correspond with the – often prolonged – process of disease emergence in a population. The disease may only occur after a significant delay in time, often decades in the case of cancer. Often, little may be known about the concentrations of contaminants which produce epidemiological effects in human populations, or the time period between the exposure and an expected effect. Reliance on, or inferences based on, past measurements may also be problematic because of inaccuracies in the historical data.

The last group of epidemiological studies use *intervention-based (or experimental) designs.* Such studies compare a group of subjects who receive an intervention (the "treatment group") versus a group who receive another (or no) intervention (the "control group"). Often there is a process of random assignment of participants into these two groups. For example, a new cholesterol-lowering tablet may be compared to an alternative form of medication to determine whether there is significant difference on the rates of a subsequent cardiovascular event (such as a heart attack). Environmental epidemiological studies often do not use experimental interventions because it is difficult to manipulate environmental variables on a large scale, and the interventions may be unethical if the safety or wellbeing of either the "treatment" or "control" group is jeopardised.

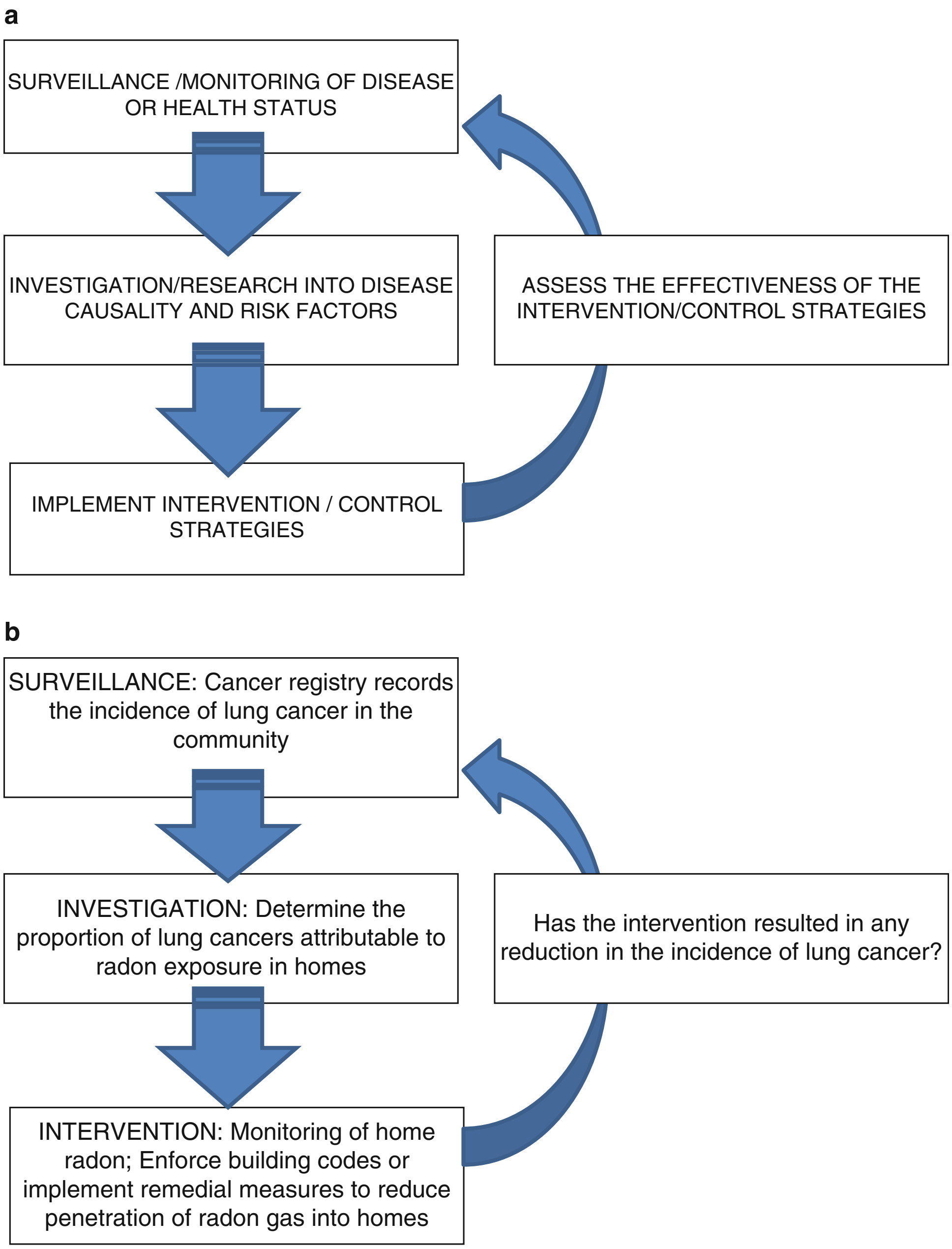

Fig. 2.5 (**a**) Schema of the main elements of a public health system. (**b**) Public health in a medical geology context: Radon exposure in the home and lung cancer

2.9 Integration and Application

In summary, geological and geochemical dynamics are integral to most of Earth's systems, and should be incorporated into existing descriptions and models of public health. The discipline of medical geology emphasises the fundamental degree to which geological processes are interconnected with the wellbeing of human communities. In many situations, patterns of disease emergence must directly or indirectly take account of geologically-driven determinants. Maintenance of wellbeing in human populations relies upon effective monitoring and management of the geosphere, especially given that anthropogenic interventions can accelerate the nature and pace of change. An integrative framework is required to evaluate, investigate and manage potential risks to communities, and must incorporate knowledge from both earth sciences and health sciences.

The core elements of the public health system can be conceptualised in Fig. 2.5a.

As noted, there are many applications of medical geology that have direct relevance to the field of public health. An integrative example will be provided here, emphasising the major themes and inter-disciplinary links covered in this chapter.

A major risk to human populations is the radioactive gas, radon, which has been linked to lung cancer. Radon-222 is a naturally occurring decay product of uranium-238 which is commonly found in soils and rocks. Radon-222 progeny, particularly polonium-218, lead-214, and bismuth-214, are of health importance because they can be inspired and retained in the lung. Public health agencies rank residential radon-222 exposure as one of the leading causes of lung cancer after tobacco smoking. An example of how the main components of a public health system relate to the issue of radon exposure in the home and lung cancer is provided in Fig. 2.5b.

See Also the Following Chapters. Chapter 3 (Natural Distribution and Abundance of Elements) • Chapter 12 (Arsenic in Groundwater and the Environment) • Chapter 19 (Natural Aerosolic Mineral Dusts and Human Health) • Chapter 24 (Environmental Medicine) • Chapter 25 (Environmental Pathology).

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Medical Geology: Perspectives and Prospects

1

Brian E. Davies, Charlotte Bowman, Theo C. Davies, and Olle Selinus

Contents

This chapter is a brief history of medical geology—the study of health problems related to "place." This overview is not exhaustive; instead, it highlights some important cases that have arisen during the development of the science of medical geology. An excess, deficiency or imbalance of inorganic elements originating from geological sources can affect human and animal well-being either directly (e.g., a lack of dietary iodine leading to goiter) or indirectly (e.g., effect on metabolic processes such as the supposed protective effect of selenium in cardiovascular disease). Such links have long been known but were unexplained until alchemy evolved into chemistry in the seventeenth century, when medicine ceased to be the art of monks versed in homeopathic remedies and experimental explanations of disease was sought rather than relying on the writings of the Classical Greek philosophers, and modern geology was forged by Lyell and Hutton. In addition, the exploitation of mineral resources gathered pace in the seventeenth century and brought in its train the widespread release of toxic elements to the environment. New sciences of public health and industrial hygiene emerged and their studies have helped inform our understanding of the health implications of the natural occurrence of these elements.

1.1 The Foundations of Medical Geology

1.1.1 Ancient Reports

Many ancient cultures made reference to the relationship between environment and health. Often health problems were linked to occupational environments but close links to the natural environment were also noted. Chinese medical texts dating back to the third century BC contain several references to relationships between environment and health. During both the Song Dynasty (1000 BC) and the Ming Dynasty (Fourteenth to Seventeenth century AD), lung problems related to rock crushing and symptoms of occupational lead poisoning were recognized. Similarly, the Tang

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Dynasty alchemist Chen Shao-Wei stated that lead, silver, copper, antimony, gold and iron were poisonous (see discussion in Nriagu, 1983).

Contemporary archaeologists and medical historians have provided us with evidence that the poor health often revealed by the tissues of prehistoric cadavers and mummies can commonly be linked to detrimental environmental conditions of the time. Goiter, for example, which is the result of severe iodine deficiency, was widely prevalent in ancient China, Greece, and Egypt, as well as in the Inca state of Peru. The fact that this condition was often treated with seaweed, a good source of iodine, indicates that these ancient civilizations had some degree of knowledge with regard to the treatment of dietary deficiencies with natural supplements.

As early as 1,500 years ago, certain relationships between water quality and health were known:

> Whoever wishes to investigate medicine properly, should proceed thus....We must also consider the qualities of the waters, for as they differ from one another in taste and weight, so also do they differ much in their quality (Hippocrates 460–377 BC).

Hippocrates, a Greek physician of the Classical period, recognized that health and place are causally related and that environmental factors affected the distribution of disease (Låg 1990; Foster 2002). Hippocrates noted in his treatise *On Airs, Waters, and Places* (Part 7) that, under certain circumstances, water "comes from soil which produces thermal waters, such as those having iron, copper, silver, gold, sulphur, alum, bitumen, or nitre," and such water is "bad for every purpose." Vitruvius, a Roman architect in the last century BC, noted the potential health dangers related to mining when he observed that water and pollution near mines posed health threats (cited in Nriagu 1983). Later, in the first century AD, the Greek physician Galen reaffirmed the potential danger of mining activities when he noticed that acid mists were often associated with the extraction of copper (cited in Lindberg 1992).

An early description linking geology and health is recounted in the travels of Marco Polo and his Uncle Niccoló. Journeying from Italy to the court of the Great Khan in China in the 1270s they passed to the south and east of the Great Desert of Lop:

> At the end of the ten days he reaches a province called Su-chau....Travelers passing this way do not venture to go among these mountains with any beast except those of the country, because a poisonous herb grows here, which makes beasts that feed on it lose their hoofs; but beasts born in the country recognize this herb and avoid it (Latham 1958).

The animal pathology observed by Marco Polo that resulted from horses eating certain plants was similar to a condition that today we know is caused by the consumption of plants in which selenium has accumulated; this explorer's account may be the earliest report of selenium toxicity. Marco Polo also described goiter in the area around the oasis city of Yarkand (Shache) and ascribed it to a peculiarity of the local water. Earlier, near Kerman on the Iranian eastern frontier, he commented on a lack of bellicosity in the tribesmen that he attributed to the nature of the soil. In what could be considered the first public health experiment, Marco Polo imported soil to place around the tribe's tents in an effort to restore their bellicosity. His approach proved to be effective (see also Chap. 16).

Health problems resulting from the production of metal have been identified in many parts of the world. The common use of metals in ancient societies suggested their toxicity. Although the relationship between lead and a variety of health risks is now well documented in modern society, the relationship was less well known in the past. Lead has been exploited for over six millennia, with significant production beginning about 5,000 years ago, increasing proportionately through the Copper, Bronze, and Iron Ages, and finally peaking about 2,000 years ago (Hong et al. 1994; Nriagu 1998). Several descriptions of lead poisoning found in texts from past civilizations further corroborate the heavy uses of lead. Clay tablets from the middle and late Assyrian periods (1550–600 BC) provide accounts of lead-poisoning symptoms, as do ancient Egyptian medical papyri and Sanskrit texts dating from over 3,000 years ago (Nriagu 1983). About 24% of discovered lead reserves were mined in ancient times (Nriagu 1998).

It has been estimated that during the time of the Roman Empire the annual production of lead approached 80,000 tonnes (Hong et al. 1994; Nriagu 1998), and copper, zinc and mercury were also mined extensively (Nriagu 1998). Lead usage exceeded 550 g per person per year, with the primary applications being plumbing, architecture, and shipbuilding. Lead salts were used to preserve fruits and vegetables, and lead was also added to wine to stop further fermentation and to add color or bouquet (Nriagu 1983). The use of large amounts of lead in the daily life of Roman aristocracy had a significant impact on their health, including epidemics of plumbism, high incidence of sterility and stillbirths and mental incompetence. Physiological profiles of Roman emperors who lived between 50 and 250 BC suggest that the majority of these individuals suffered from lead poisoning (Nriagu 1983)., It has been claimed that a contributing factor to the fall of the Roman Empire, in AD 476, may have been the excessive use of lead in pottery, water pipes and other sources (Hernberg 2000).

Mercury was used during the Roman Empire to ease the pain of teething infants, as well as to aid in the recovery of gold and silver. Such applications were also widely found in Egypt in the twelfth century and in Central and South America in the sixteenth century (Eaton and Robertson 1994; Silver and Rothman 1995). Mercury was used to treat syphilis during the sixteenth century and in the felting process in the 1800s (Fergusson 1990).

Copper was first used in its native form approximately 7,000 years ago, with significant production beginning some

2,000 years later and eventually peaking at a production rate of about 15,000 tonnes annually during the Roman Empire, when it was used for both military and civilian purposes, especially coinage. A significant drop in the production of copper followed the fall of the Roman Empire, and production remained low until about 900 years ago when a dramatic increase in production occurred in China, reaching a maximum of 13,000 tonnes annually and causing a number health problems (Hong et al. 1994).

Arsenic was used for therapeutic purposes by the ancient Greeks, Romans, Arabs, and Peruvians, because small doses were thought to improve the complexion; however, it has also long been used as a poison (Fergusson 1990). In the sixteenth century, Georgius Agricola (Agricola 1556) described the symptoms of "Schneeberger" disease among miners working in the Erzgebirge of Germany to mine silver in association with uranium. That disease has since been identified as lung cancer deriving from metal dust and radon inhalation.

1.1.2 More Recent Reports

The industrial revolution in Europe and North America encouraged people to quit the poverty of subsistence agriculture in the countryside to live in increasingly crowded cities where they found work in factories, chemical plants and foundries; however, such occupations exposed the workers to higher levels of chemical elements and compounds that, as rural dwellers, they would rarely have encountered. Friedrich Engels wrote graphic descriptions of the ill health of the new English proletariat in his politically seminal book, *The Conditions of the Working Class in England*, published in 1845. He described the plight of children forced to work in the potteries of Staffordshire: "By far the most injurious is the work of those who dip. . .into a fluid containing great quantities of lead, and often of arsenic.... The consequence is violent pain, and serious diseases of the stomach and intestines. . .partial paralysis of the hand muscles. . .convulsions" (Engels 1845). Engels further characterized the conditions of workers in mid-nineteenth century industrial England as "want and disease, permanent or temporary."

The sciences of toxicology and industrial medicine arose in response to the health problems caused by unregulated industrialization. These sciences have provided the clinical data that allow us to understand the consequences of excess exposure to elements in the natural environment, whether it be due to simple exposure to particular rocks or the exploitation of mineral resources. The emergence of modern geological sciences coupled with increasingly powerful analytical techniques laid the foundation for determining the nature and occurrence of trace elements in rocks and sediments. Scientific agriculture has focused attention on inorganic element deficiencies in plants and animals. Modern medicine has provided reliable descriptions of diseases and more accurate diagnoses through internationally recognized nomenclatures.

Rural people have always recognized that the health of domesticated animals is influenced by drinking water or diet and, therefore, soil properties. These observations could not be explained until the advent of scientific agriculture in the nineteenth century, when it required only a small step to suggest that humans may also be caught up in similar relationships. Diseases now known to be caused by a lack or excess of elements in soil and plants were given names that reflected where they occurred, such as Derbyshire neck in the iodine-deficient areas of the English Midlands or Bodmin Moor sickness over the granites of southwest England where cobalt deficiency is endemic in sheep unless treated. It is interesting to note that in Japan, before the 1868 Meiji Restoration, meat was rarely eaten so there was no tradition of animal husbandry. Japanese authors have suggested that this lack of animal indicators largely contributed to the failure to recognize the significance of metal pollution until it became catastrophic.

Archaeologists have also noted links between health and environmental factors. Analysis of bone material has provided an excellent tool for studying the diet and nutritional status of prehistoric humans and animals (Krzysztof and Glab 2001). For example, the transition from a hunter–gatherer society to an agriculturally based economy resulted in a major dietary change and an accompanying iron deficiency. Iron in plants is more difficult to absorb than iron from a meat source; hence, it has been proposed that this new reliance on a crop diet may have resulted in iron deficiency and anemia among the general population (Roberts and Manchester 2007).

Skeletal remains found in Kentucky have provided prime examples of the relationship between geology and ancient human health. Native Americans established permanent settlements in the area and began normal crop cultivation practices. As a result of soil micronutrient deficiencies, their maize contained extremely low levels of zinc and manganese. These deficiencies led to a range of diet-related health effects that have been clearly documented through the study of dental and skeletal pathology in human remains (Moynahan 1979).

Several landmark discoveries in medical geology have been made in Norway. For a long time, Norwegian farmers have been aware of the unusually frequent occurrence of osteomalacia among domestic animals in certain districts, and to combat the disease they initiated the practice of adding crushed bones to the feed of the animals. Some farmers suspected that a particular pasture plant caused osteomalacia, and a Norwegian official named Jens Bjelke (1580–1659), who had an interest in botany and a knowledge of foreign languages, gave the suspected plant the Latin name *Gramen ossifragum* (“the grass that breaks bones”). The name has also been *written Gramen Norwagicum ossifragum.*

One hundred years ago, the geologist J. H. L. Vogt learned of the practice of adding crushed bones to the diets of farm animals and investigated a region where osteomalacia was common. When he found very small amounts of the mineral apatite in the rocks, he drew the logical and correct conclusion that a deficiency of phosphorus was the cause of the osteomalacia. Another Norwegian geologist (Esmark 1823) had previously pointed out that vegetation was extraordinarily sparse over the bedrock which was found by Vogt to be very poor in apatite. Once the cause of the osteomalacia was determined, it became a relatively simple matter to prevent the damage by adding phosphorus fertilizer to the soil (Låg 1990) (see also Chap. 15, this volume).

A significant publication was André Voisin’s book, *Soil, Grass and Cancer* (1959), especially in light of today’s interest in the dangers of free radicals in cells and the protective effects of antioxidant substances and enzymes. Over 40 years ago, Voisin stressed the protective role of catalase and observed that copper deficiency was accompanied by low cytochrome oxidase activity.

Oddur Eiriksson and Benedikt Pjetursson provided detailed descriptions of the damage to teeth of domestic animals that resulted from the eruption of the Icelandic volcano Hekla in 1693. At that time it was not known that the cause was fluorosis. The relationship between the incidence of fluorine deficiency and dental caries has been carefully studied in Scandinavia since World War II, with attention being particularly centered around the need for fluoridation of water. Analyses of the fluoride content of natural waters from various sources and their relationships to the frequency of caries have been reported from several districts (see also Chap. 10, this volume).

1.2 Geochemical Classification of the Elements

The principles of geochemistry and, hence, medical geology were established at a time when modern analytical techniques were in their infancy and most scientists relied on the very laborious classical chemical approaches. Despite the limitations imposed by a lack of rapid analysis of rocks and soils, the basic principles of geochemistry were known by the start of the twentieth century. In 1908, Frank W. Clarke, of the U.S. Geological Survey, published the original edition of *The Data of Geochemistry*, in which he adopted a systems approach to present his information. Clarke’s book was the forerunner of several texts published during the first half of the twentieth century that have helped us understand how geochemistry is linked to health. Arguably the most important text of the period was V. Goldschmidt’s *Geochemistry* (1954), which was based on work by Linus Pauling; it was completed by Alex Muir in Scotland and published after Goldschmidt’s death in 1947. Two of Goldschmidt’s ideas are of special relevance to medical geology: his geochemical classification of the elements and his recognition of the importance of ionic radii in explaining “impurities” in natural crystals.

Table 1.1 Geochemical classification of elements

Group	Elements
Siderophile	Fe, Co, Ni, Pt, Au, Mo, Ge, Sn, C, P
Atmophile	H, N, O
Chalcophile	Cu, Ag, Zn, Cd, Hg, Pb, As, S, Te
Lithophile	Li, Na, K, Rb, Cs, Mg, Ca, Sr, Ba, Al, rare earths (REE)

Goldschmidt’s geochemical classification groups elements into four empirical categories (Table 1.1). The *siderophilic* elements are those primarily associated with the iron–nickel (Fe–Ni) core of the Earth; these elements may be found elsewhere to some extent, but this classification explains why, for example, platinum and associated metals are normally rare and dispersed in crustal rocks. This fundamental geochemical observation allowed Alvarez et al. (1980) to recognize the significance of the high iridium contents of clays found at the Cretaceous/Tertiary (K/T) boundary. They proposed the persuasive idea that the impact of an asteroid (Fe–Ni type) on the surface of the Earth could explain the massive species extinctions that define the K/T boundary, including the demise of the dinosaurs. Was this an example of medical geology on a global scale?

The *atmophilic* elements are those dominating the air around us, and *lithophilic* elements are common in crustal silicates (Alvarez et al. 1980). Of special interest are the *chalcophilic* elements, which derive their name from a geochemical grouping of these elements with copper (Greek χαλκός). These elements are encountered locally in high concentrations where recent or ancient reducing conditions (and hydrothermal conditions) have led to the reduction of sulfate to sulfide, resulting in the formation of sulfide minerals such as pyrite (FeS_2) and the ores of lead (galena, PbS) or zinc (sphalerite, ZnS). This same thiophilic tendency underlies the toxicity of lead, mercury, and cadmium because they readily link to the —SH groups of enzymes and thereby deactivate them. Goldschmidt’s empirical classification of chalcophilic elements is now reinterpreted in terms of hard and soft acids and bases; soft bases (e.g., R—SH or $R—S^-$) preferentially bind to soft acids (e.g., Cd^{2+} or Hg^{2+}).

Goldschmidt's (and Pauling's) second important concept was the importance of ionic size in explaining both the three-dimensional structures of silicate crystals and how other elements can become incorporated in them. The rules are now generally known as *Goldschmidt's rules of substitution*:

1. The ions of one element can replace another in ionic crystals if their radii differ by less than about 15%.
2. Ions whose charges differ by one unit can substitute provided electrical neutrality of the crystal is maintained.
3. For two competing ions in substitution, the one with the higher ionic potential (charge/radius ratio) is preferred.
4. Substitution is limited when competing ions differ in electronegativity and form bonds of different ionic character.

These rules of substitution and the geochemical classification of elements are fundamental to our growing understanding of medical geology, for they explain many environmental occurrences of toxic elements and allow scientists to predict where such occurrences might be found.

1.3 Contributions to Medical Geology from Public Health and Environmental Medicine

Although most public health problems involve diseases caused by pathogens, inorganic elements and their compounds can also affect public health; among these elements are arsenic, cadmium, and mercury. The effects of mercury on human health can be traced back several centuries. For example, in the sixteenth century and later, mercury and its compounds were widely used to treat syphilis despite its known toxicity (D'itri and D'itri 1977), and mercuric nitrate solution was used to soften fur for hat making. Long-term exposure caused neurological damage in workers handling mercury and gave rise to expressions such as "mad as a hatter" or the "Danbury shakes." In Birmingham, England, buttons were gilded by exposing them to a gold–mercury (Au–Hg) amalgam followed by vaporization of the mercury. By 1891, many tons of mercury had been dissipated around Birmingham, to the great detriment of that city's inhabitants, many of whom suffered from "Gilder's palsy". Neurological damage due to exposure to inorganic mercury compounds was well understood by the end of the nineteenth century. In recent decades there has been concern about environmental levels of mercury in Amazonia, where the amalgamation of gold by mercury in small-scale mining operations has caused widespread mercury pollution

Modern concerns are focussed on methyl mercury, a lipid-soluble organic compound that concentrates up the food chain. Recognition of such a problem resulted from the outbreak of methylmercury poisoning in 1956 in Minamata city in Japan, thus the name used today—Minamata disease (Harada 1995). Subsequently, methylmercury poisoning has been observed in, for example, Niigata (Japan), Sweden, Iraq, and the United States. In the USA mercury emissions from coal burning have led to restrictions on lake and river fishing (EPA 2011).

Concern about environmental cadmium can be traced back to the outbreak of itai itai disease in Japan earlier in the twentieth century (Chaney et al. 1998). The disease resulted in severe bone malformations in elderly women, and a zinc mine in the upper reaches of the Jintsu river was found to be the source of the cadmium that caused the disease. Later, cadmium was found to be linked to kidney damage, and the element was found to build up in soil following the application of some sewage sludges. Many countries now control the land application of sludge and have set limits in terms of permissible cadmium additions (Friberg et al. 1974).

The coloured compounds of arsenic were used as pigments as early as the Bronze Age, and knowledge of its toxicity is just as old. Of concern today are the skin lesions and cancers observed among the millions of people drinking arsenic-rich well water, especially in West Bengal and Bangladesh. As with mercury, links between arsenic and certain cancers were identified early on. Fowler's solution, which contained potassium arsenite, was widely prescribed as a tonic. Patients who believed that if a little of something (a few drops) would do them good then a lot of it must do them a lot of good and tended to overdose on the solution. By the late eighteenth century, it was recognized that injudicious use of Fowler's solution led first to peripheral neuritis, which was followed by skin lesions and cancer (see also Chaps. 12 and 25, this volume).

Coal is a sedimentary rock formed by the diagenesis of buried peats, which, in turn, form from organic debris under wet, reducing conditions. This process favors the precipitation of the sulfides of chalcophilic metals (especially pyrite, FeS_2). Pyrite can contain significant concentrations of arsenic as well as mercury, thallium, selenium, nickel, lead, and cobalt. Incineration of coal releases mercury to the atmosphere; sulfur gases, which cause acid precipitation, and arsenic compounds may also be released or remain in the ash.

In the autumn of 1900, an epidemic of arsenic poisoning occurred among beer drinkers in Manchester, Salford, and Liverpool in England. The poisoning was first traced to the use of sulfuric acid to make the glucose required for the brewing process; apparently, the breweries had unknowingly switched from de-arsenicated acid (sulfuric acid is a valuable by-product of smelting industries, including those dealing with arsenic ores). Additionally, however, malted barley was dried over coal fires, which contributed to the problem. Even moderate beer drinkers suffered from peripheral neuritis and shingles (herpes zoster), which can be induced by arsenic exposure. Arsenic poisoning has recently emerged again in China, where severe arsenic poisoning has been reported in recent years as a result of consumption of vegetables dried over coal fires (Finkelman et al. 1999).

1.4 Development of Medical Geology

1.4.1 The Knowledge Gained from Single-Element Studies

Over the course of the twentieth century, geoscientists and epidemiologists gained a greater understanding of the many ways in which the environment of Earth can affect the health of its inhabitants. Incidents of metal poisoning and the identification of specific relationships between dietary constituents and health became representative examples of more general human reactions to exposures to the geochemical environment. The clearest example of the relationship between geology and health is when the presence of too much or too little of a single element in the environment is found to cause or influence disease as a result of being transferred into the body through dust in the soil or air or via water or food.

Iodine remains the classic success story in medical geology as far as human health is concerned. The most common health effect associated with an iodine deficiency is goiter, a swelling of the thyroid gland. Late in the nineteenth century, it was determined that iodine concentrates in the thyroid gland, but the iodine concentrations were reduced in the thyroids of patients from endemic goitrous areas. Iodine deficiency disorders (IDDs) remain a major threat to the health and development of populations the world over. Clinical treatment of IDDs is, of course, the prerogative of medical doctors; nonetheless, a greater understanding of the conditions leading to IDDs has resulted from the work of geoscientists. (Iodine is described in detail in Chap. 17.)

The study of arsenic remained the province of toxicology and forensic medicine until the middle twentieth century. A paper on arsenic in well water in the Canadian Province of Ontario stated: “The occurrence of arsenic in well water is sufficiently rare to merit description” (Wyllie 1937). Pictures accompanying the text illustrate keratosis on the feet and the palm of a hand. It was concluded in the article that the occurrence of arsenic poisoning from well water was infrequent. Less than 40 years later, however, the scientific world learned of “blackfoot disease” in the Republic of China (Taiwan), and skin disorders and cancer due to arsenic-polluted well water have been described in Chile, Mexico, and Argentina. Serious problems are currently being reported in West Bengal and Bangladesh. In all cases, the geological link is clear (described in detail in Chaps. 12 and 25).

Cobalt deficiency provides a good example of the relationship between animal health and the geological environment. In New Zealand, cobalt deficiency was known as “bush sickness” or Morton Mains disease; in Kenya, as *nakuruitis*; in England, as pining; in Denmark, as *vosk* or *voskhed*; and in Germany, as *hinsch*. The underlying cause was discovered by Dr. Eric Underwood, an early expert in the medical geology field (Underwood and Filmer 1935). His discovery in 1935 of the essentiality of cobalt is an example of triumph over analytical difficulty. Underwood and Filmer showed that “enzootic marasmus” could be cured by treatment with an acid extract of the iron oxide limonite, from which all but negligible quantities of iron had been removed using the laborious methods of classical qualitative analysis. In all cases, the problem can be traced back to a low cobalt content of the soil parent material. Inadequate cobalt is passed up the food chain for microflora in the gut of herbivores to use in the synthesis of the essential cobalt-containing cobalamin or vitamin B_{12}. Only one case of human cobalt deficiency appears to have been published (Shuttleworth et al. 1961). A 16 month-old girl on an isolated Welsh hill farm was a persistent dirt eater and suffered from anemia and behavioral problems. The cattle on the farm were being treated for cobalt deficiency, and the child recovered her health after oral administration of cobaltous chloride.

Lead poisoning has dominated the environmental agenda for several decades. It is interesting to note that geologists were aware of the potential health problems associated with lead when medical opinion on the subject was still mixed. In mid-nineteenth century Britain, residents expressed growing concern about the unregulated disposal of mine and industrial wastes in rivers. In west Wales, farmers complained that lead mining was ruining their fields as a result of the deposition of polluted sediment when rivers flooded. A Royal Commission in 1874 evaluated their complaints, and legislation soon followed (River Pollution Prevention Act, 1878); however, it was too late. Well into the twentieth century, cattle poisoning in the Ystwyth valley of west Wales continued to occur due to the earlier contamination by mines in the previous century. As late as 1938, the recovery of these rivers was monitored, and even in the 1970s evidence of past pollution was still evident (Davies and Lewin 1974). It was the late Professor Harry Warren in Vancouver, Canada, who first recognized the important implications of high levels of environmental lead. He devoted the last 30 years of his professional life to arguing for the significance of lead uptake by garden vegetables and its possible role in the etiology of multiple sclerosis. Warren had pioneered the use of tree twigs in prospecting for mineral ores in British Columbia, Canada, and he was surprised to observe that lead contents were often higher in forests bordering roads and concluded that "industrial salting" was a widespread and serious problem. Nonetheless, until the 1960s, environmental lead remained a mere curiosity. Health problems were thought to occur only from industrial exposure or due to domestic poisoning from lead dissolved by soft water from lead pipes.

Over the past 20 years, the removal of lead from gasoline, food cans, and paint has reduced US population blood lead levels by over 80%. Milestones along the way included evidence that dust on hands and direct soil consumption (pica) by children represented a major pathway of lead exposure (Gallacher et al. 1984). The phasing out of lead in gasoline in the United States was accompanied by a general reduction in blood lead levels (Mahaffey et al. 1982). Adding to the debate was the contention that even relatively low levels of lead exposure could harm the development of a child's brain (Davies and Thornton 1989; Nriagu 1983; Ratcliffe 1981; Warren and Delavault 1971).

The medical geology of selenium provides a good example of the interaction between geology and medicine. In the late 1960s, selenium was shown to be essential for animals and to be an integral part of glutathione oxidase, an enzyme that catalyzes the breakdown of hydrogen peroxide in cells (Prasad 1978). In sheep and cattle, a deficiency in selenium accounted for "white muscle disease" (especially degeneration of the heart muscle), and glutathione peroxidase activity was found to be a good measure of selenium status. The problem was particularly widespread among farm animals in Great Britain (Anderson et al. 1979). Humans have also been shown to suffer from selenium deficiency, and in China this condition is referred to as Keshan disease (Rosenfeld and Beath 1964; Frankenberger and Benson 1994; Frankenberger and Engberg 1998). The disease has occurred in those areas of China where dietary intakes of selenium are less than 0.03 mg/day because the selenium content of the soils is low. The condition is characterized by heart enlargement and congestive heart failure. The disease has been primarily seen in rural areas and predominantly among peasants and their families. Those most susceptible have been children from 2 to 15 years of age and women of child-bearing age (Chen et al. 1980; Jianan 1985). Also, it has been suggested that adequate selenium intake may be protective for cancers (Diplock 1984), and self-medication with selenium supplements has become widespread with the belief that a lack of selenium is a risk factor in heart diseases. (Selenium is described in greater detail in Chap. 16.)

1.4.2 The Importance of Element Interactions is Recognized

The number of productive single-element studies has obscured two fundamental geochemical principles: First, from a geochemistry perspective, elements tend to group together, and, second, the study of physiology recognizes that elements can be synergistic or antagonistic. Cadmium is a good example of both principles. In some environments, soil cadmium levels are high because of rock type (such as black shales) or from mining contamination. A highly publicized polluted environment is that of the village of Shipham, which in the eighteenth century was a thriving zinc mining village in the west of England.

A study in 1979 suggested that 22 out of 31 residents showed signs of ill health that could be traced to cadmium (Carruthers and Smith 1979). As a result, the health of over 500 residents was subsequently assessed and compared with that of a matching control population from a nearby non-mining village, but "there was no evidence of adverse health effects in the members of the population studied in Shipham" (Morgan and Simms 1988, Thornton et al. 1980). Chaney et al. (1998) have commented on the disparity between the reports of ill health in Japan and no-effect observations from other parts of the world: "research has shown that Cd transfer in the subsistence-rice food-chain is unique, and that other food-chains do not comprise such high risk per unit soil Cd" and "Evidence indicates that combined Fe and Zn deficiencies can increase Cd retention by 15-fold compared to Fe and Zn adequate diets…it is now understood that rice grain is seriously deficient in Fe, Zn, and Ca for human needs".

Copper and molybdenum taken individually and together demonstrate the importance of not relying upon simple single-cause relationships. In Somerset (England) there is an area in which pasture causes scouring in cattle. The land is known locally as "teart" and was first reported in the scientific literature in 1862 (Gimingham 1914), but the cause of the disorder (molybdenum) was not ascertained until 1943 (Ferguson et al. 1943), when it was shown that the grass contained 20–200 mg molybdenum per kg (d.m.) and that the disorder could be cured by adding cupric sulfate to the feed. The origin of the excess molybdenum was the local black shales (Lower Lias) (Lewis 1943). Over 20 years later, geochemical reconnaissance of the Lower Lias throughout the British Isles showed that elevated molybdenum contents in soils and herbage were a widespread problem over black shale, regardless of geological age, and that this excess molybdenum was the cause of bovine hypocuprosis (Thornton et al. 1966, 1969; Thomson et al. 1972). A moose disease in Sweden provides another example of the effects of molybdenum, in this case resulting from the interaction of molybdenum with copper.

This disease is covered in detail in Chap. 21 (see also Kabata-Pendias and Pendias 1992; Kabata-Pendias 2001; Adriano 2001).

1.4.3 Mapping Diseases as a Tool in Medical Geology

Medical geology benefits from the work of medical geographers who have mapped diseases in different countries. For some important groups of diseases (e.g., cancers, diseases of the central nervous system, and cardiovascular disease), the causes are by and large uncertain. When the incidence or prevalence of these diseases has been mapped, especially in countries of western Europe, significant differences from place to place have been reported that are not easily explained by genetic traits or social or dietary differences. Howe (1963) pioneered the use of standardized epidemiological data in his 'National Atlas of Disease Mortality in the United Kingdom'. His stomach cancer maps clearly identified very high rates in Wales. Environmental influences appear to be involved in the etiologies, and a role for geology has been suggested by many authors (see, for example, Chap. 14). An early study of gastrointestinal cancer in north Montgomeryshire, Wales (Millar 1961) seemed to show an association with environmental radioactivity because local black shales were rich in uranium. There was no direct evidence to support the hypothesis, and the study was marked by a problem of earlier work—namely, an indiscriminate use of statistics. Work in 1960 in the Tamar valley of the west of England appeared to show that mortality from cancer was unusually low in certain villages and unusually high in others (Davies 1971). Within the village of Horrabridge, mortality was linked to the origin of different water supplies: The lowest mortality was associated with reservoir water from Dartmoor, whereas the highest mortality was associated with well or spring water derived from mineralized rock strata. Although this study was again statistically suspect, it stimulated a resurgence of interest in the link between cancer and the environment.

Stocks and Davies (1964) sought direct associations between garden soil composition and the frequency of stomach cancer in north Wales, Cheshire, and two localities in Devon. Soil organic matter, zinc, and cobalt were related positively with stomach cancer incidence but not with other intestinal cancer. Chromium was connected with the incidence of both. The average logarithm of the ratio of zinc/copper in garden soils was always higher where a person had just died of stomach cancer after 10 or more years of residence than it was at houses where a person had died similarly of a nonmalignant cause. The effect was more pronounced and consistent in soils taken from vegetable gardens, and it was not found where the duration of residence was less than 10 years.

Association is not necessarily evidence for cause and effect. For mapping approaches to be reliable, two conditions must be satisfied. First, it is essential to be able to show a clear pathway from source (e.g., soil) to exposure (e.g., dirt on hands) to assimilation (e.g., gastric absorption) to a target organ or physiological mechanism (e.g., enzyme system). The second condition, rarely satisfied, is that the hypothetical association must be predictive: If the association is positive in one area, then it should also be positive in a geologically similar area; if not, why not? This condition is well illustrated by fluoride and dental caries—environments where fluoride is naturally higher in drinking water have consistently proved to have lower caries rates.

A possible link between the quality of water supply, especially its hardness, was the focus of much research in the 1970s and 1980s. This was noticed, for example, in Japan in 1957. A statistical relationship was found between deaths from cerebral hemorrhage and the sulfate/carbonate ratio in river water which, in turn, reflected the geochemical nature of the catchment area. In Britain, calcium in water was found to correlate inversely with cardiovascular disease, but the presence of magnesium did not; thus, hard water may exercise some protective effect. Attention has also been paid to a possible role for magnesium, because diseased heart muscle tissue is seen to contain less magnesium than healthy tissue. Still, it has to be pointed out that hard waters do not necessarily contain raised concentrations of magnesium; this occurs only when the limestones through which aquifer water passes are dolomitized, and most English limestones are not. More details can be found in Chap. 14.

Mapping diseases has also been a valuable tool for a long time in China, where pioneering work has been done by Tan Jianan (1989). Modern mapping techniques are now widely used in medical geology; mapping and analytical approaches to epidemiological data are covered in Cliff and Haggett (1988), while discussions on using GIS and remote sensing, as well as several examples, are offered in Chaps. 28 and 29.

1.4.4 Dental Health Provides an Example of the Significance of Element Substitutions in Crystals

Dental epidemiology has provided some of the most convincing evidence that trace elements can affect the health of communities (Davies and Anderson 1987). Dental caries is endemic and epidemic in many countries, so a large population is always available for study. Because diagnosis relies upon a noninvasive visual inspection that minimizes ethical restrictions, a high proportion of a target population can be surveyed. Where the survey population is comprised of children (typically 12 year olds), the time interval between supposed cause and effect is short, and it is possible to make direct associations between environmental quality and disease prevalence. In the case of fluoride, a direct link was established over 50 years ago that led to the successful fluoridation of public water supplies. This is an example of medical geology influencing public health policy. The relationship between dental caries and environmental fluoride, especially in drinking water, is probably one of the best known examples of medical geology. So strong is the relationship that the addition of 1 mg of fluoride per liter to public water supplies has been undertaken regularly by many water utilities as a public health measure.

The history of the fluoride connection is worth recounting. In 1901, Dr. Frederick McKay opened a dental practice in Colorado Springs, Colorado, and encountered a mottling and staining of teeth that was known locally as "Colorado stain." The condition was so prevalent that it was regarded as commonplace but no reference to it could be found in the available literature. A survey of schoolchildren in 1909 revealed that 87.5% of those born and reared locally had mottled teeth. Inquiries established that an identical pattern of mottling in teeth had been observed in some other American areas and among immigrants coming from the volcanic areas of Naples, Italy. Field work in South Dakota and reports from Italy and the Bahamas convinced McKay that the quality of the water supply was somehow involved in the etiology of the condition. He found direct evidence for this in Oakley, Idaho, where, in 1908, a new piped water supply was installed from a nearby thermal spring and, within a few years, it was noticed that the teeth of local children were becoming mottled. In 1925, McKay persuaded his local community to change their water supply to a different spring, after which stained teeth became rare.

A second similar case was identified in Bauxite, Arkansas, where the water supply was analyzed for trace constituents, as were samples from other areas. The results revealed that all the waters associated with mottled teeth had in common a high fluoride content 2–13 mg of fluoride per liter. In the 1930s, it was suggested that the possibility of controlling dental caries through the domestic water supply warranted thorough epidemiological-chemical investigation. The U.S. Public Health Service concluded that a concentration of 1 mg fluoride per liter drinking water would be beneficial for dental health but would not be in any way injurious to general health. Fluoride was first added to public water supplies in 1945 in Grand Rapids, Michigan. Fluoridation schemes were subsequently introduced in Brantford, Ontario (1945); Tiel, The Netherlands (1953); Hastings, New Zealand (1954); and Watford, Anglesey, and Kilmarnock in Great Britain (1955). There is no doubt that whenever fluorides have been used a reduction in the prevalence of dental caries follows (Davies and Anderson 1987; Leverett 1982) (see also Chap. 13, this volume).

1.5 An Emerging Profession

The field of medical geology (or geomedicine) has developed around the world over the last few decades. The development of activities and the organizational structure of medical geology in a number of regions will be discussed in this section, including the United States, Great Britain, Scandinavia, some African countries, and China.

As research interest in medical geology grew during the 1960s, the desire emerged for conference sessions or even entire conferences dedicated to the subject. The late Dr. Delbert D. Hemphill of the University of Missouri organized the first Annual Conference on Trace Substances in Environmental Health in 1967, and these meetings continued for a quarter of a century. Early in the 1970s, several countries took the initiative to organize activities within the field of medical geology, and a symposium was held in Heidelberg, West Germany, in October 1972. In the United States, Canada, and Great Britain, research on relationships between geochemistry and health were carried out, and the Society for Environmental Geochemistry and Health (SEGH) was established. Geochemistry has for a long time maintained a strong position in the former Soviet Union, and basic knowledge of this science is routinely applied to medical investigations. Medical geology has a long tradition in northern Europe, and the development of this emerging discipline in Scandinavia has been strong. In Norway, too, geochemical research has been regarded as important for quite some time.

In North America in the 1960s and 1970s, a number of researchers made important contributions to our understanding of the role of trace elements in the environment and their health effects; among these are Helen Cannon and Howard Hopps (1972), H. T. Shacklette et al. (1972), and Harry V. Warren (1964). A meeting on environmental geochemistry and health was held and sponsored by the British Royal Society in 1978 (Bowie and Webb 1980). Another landmark date was 1979, when the Council of the Royal Society (London) appointed a working party to investigate the role in national policy for studies linking environmental geochemistry to health. This was chaired by Professor S. H. U. Bowie of the British Geological Survey (Bowie and Thornton 1985). In 1985, the International Association of Geochemistry and Cosmochemistry (IAGC) co-sponsored with the Society for Environmental Geochemistry and Health (SEGH) and Imperial College, London, the first International Symposium on Geochemistry and Health (Thornton 1985). In 1985 Professor B E Davies became editor of a journal then titled 'Minerals and the Environment', rebranded it as 'Environmental Geochemistry and Health' (Davies 1985) and formally linked it with SEGH. The journal is now published by Springer under the editorship of Professor Wong Ming Hung and is in its 34th volume.

In 1987, a meeting on geochemistry and health was held at the Royal Society in London, and in 1993 a meeting on environmental geochemistry and health in developing countries was conducted at the Geological Society in London (Appleton et al. 1996).

Traditionally, the terms *geomedicine* and *environmental geochemistry and health* have been used. Formal recognition of the field of geomedicine is attributed to Ziess, who first introduced the term in 1931 and at the time considered it synonymous with *geographic medicine*, which was defined as "a branch of medicine where geographical and cartographical methods are used to present medical research results." Little changed until the 1970s, when Dr. J. Låg, of Norway, redefined the term as the "science dealing with the influence of ordinary environmental factors on the geographic distribution of health problems in man and animals" (Låg 1990).

The Norwegian Academy of Science and Letters has been very active in the field of medical geology and has arranged many medical geology symposia, some of them in cooperation with other organizations. The proceedings of 13 of these symposia have been published. Since 1986, these symposia have been arranged in collaboration with the working group Soil Science and Geomedicine of the International Union of Soil Science. The initiator of this series of meetings was the late Dr. Låg, who was Professor of Soil Science at the Agricultural University of Norway from 1949 to 1985 and who was among the most prominent soil scientists of his generation, having made significant contributions to several scientific disciplines. During his later years, much of Dr. Låg's work was devoted to medical geology, which he promoted internationally through his book (Låg 1990).

The countries of Africa have also experienced growth in the field of medical geology. The relationships between the geological environment and regional and local variations in diseases such as IDDs, fluorosis, and various human cancers have been observed for many years in Africa. Such research grew rapidly from the late 1960s, at about the same time that the principles of geochemical exploration began to be incorporated in mineral exploration programs on the continent. In Africa, evidence suggesting associations between the geological environment and the occurrence of disease continues to accumulate (see, for example, Davies 2003, 2008; Davies and Mundalamo 2010), but in many cases the real significance of these findings remains to be fully appreciated. The reasons are threefold: (1) the paucity of reliable epidemiological data regarding incidence, prevalence, and trends in disease occurrence; (2) the lack of geochemists on teams investigating disease epidemiology and etiology; and (3) a shortage of analytical facilities for measuring the contents of nutritional and toxic elements at very low concentration levels in environmental samples (Davies 1996). Confronting these challenges, however, could prove to be exceedingly rewarding, for it is thought that the strongest potential significance of such correlations exists in Africa and other developing regions of the world. Unlike the developed world, where most people no longer eat food grown only in their own area, most of the people in Africa live close to the land and are exposed in their daily lives, through food and water intake, to whatever trace elements have become concentrated (or depleted) in crops from their farms (Appleton et al. 1996; Davies 2000).

The first real attempt to coordinate research aimed at clarifying these relationships took place in Nairobi in 1999, when the first East and Southern Africa Regional Workshop was convened, bringing together over 60 interdisciplinary scientists from the region (Davies and Schlüter 2002). One outcome of this workshop was the constitution of the East and Southern Africa Association of Medical Geology (ESAAMEG), establishing it as a chapter of the International Medical Geology Association (IMGA). The Geomed 2001 workshop held in Zambia testified to the burst of interest and research activities generated by that first workshop (Ceruti et al. 2001). As a result of this increasing awareness of medical geology problems around the continent, membership and activities of the ESAAMEG have continued to grow. This is a welcome sign on both sides of what has hitherto been an unbridged chasm between geology and health in Africa.

China has a long history of medical geology. Chinese medical texts dating back to the third century BC contain several references to relationships between geology and health. During both the Song Dynasty (1000 BC) and the Ming Dynasty (fourteenth to seventeenth century), lung ailments related to rock crushing and symptoms of occupational lead poisoning were recognized. Similarly, as noted earlier, the Tang Dynasty alchemist Chen Shao-Wei stated that lead, silver, copper, antimony, gold, and iron were poisonous.

In the twentieth century, much research has been carried out in China (for example, on the selenium-responsive Keshan and Kashin Beck diseases) that has resulted in clarification of the causes of a number of diseases, including endemic goiter and endemic fluorosis. One of the centers for this research has been the Department of Chemical Geography at the Chinese Academy of Sciences. At this institute, several publications have been produced, such as *The Atlas of Endemic Diseases and Their Environments in the People's Republic of China* (Jianan 1985). Also the Institute of Geochemistry in Guiyang in Southern China is known for its studies in the field that is now referred to as medical geology.

International Medical Geology Association, IMGA, (Fig. 1.1) (www.medicalgeology.com) in its present form was founded in January 2006, but began as an idea 10 years before in 1996 when a working group on Medical Geology

Fig. 1.1 International Medical Geology Association, IMGA

was established by International Union of Geological Sciences (Skinner and Berger 2003). Its primary aim was to increase awareness among scientists, medical specialists and the general public on the importance of geological factors for health and wellbeing. It was recognised that the limited extent of cooperation and communication among these groups restricted the ability of scientists and public health workers to solve a range of complex environmental health problems. The term "Medical Geology" was adopted in 1997.

A first short course on Medical Geology was carried out in Lusaka, Zambia and at the University of Zambia. It was decided that the short course would be brought to developing countries which faced critical Medical Geology problems. This proposal was supported by the International Commission on Scientific Unions (ICSU) and later on UNESCO in support of short courses in Medical Geology to be held in 2002–2003. Since 2001 short courses in medical geology have been held in more than 50 countries.

A first Hemispheric Conference on Medical Geology was organized in Puerto Rico in 2005. The International Medical Geology Association, IMGA, was established 2006. This year also a special symposium on Medical Geology was held at the Royal Academy of Sciences in Stockholm. The 2nd Hemispheric Conference on Medical Geology was held in Atibaya, Brazil in 2007. United Nations announced in 2008 Medical Geology as one of the themes of the International Year of Planet Earth. IMGA also had several sessions and a short course at the 33 International Geological Conference in Oslo with 7,000 participants. In 2009 IMGA was involved in 'Mapping GeoUnions to the ICSU Framework for Sustainable Health and Wellbeing' as full members. The 3rd Hemispheric Conference on Medical Geology was held in Montevideo, Uruguay and in 2011 the 4th International conference in medical geology was organised in Italy with more than 400 participants.

The development of medical geology has been tremendous and education has started at several universities and medical geology is on the agenda all over the world with many active local chapters spread in all continents (Selinus et al. 2010).

1.6 Prospects

As we progress into the early years of the twenty-first century, it can be safely claimed that medical geology has emerged as a serious professional discipline. If respect for medical geology as a discipline is to continue to grow, then future studies must go well beyond simplistic comparisons of geochemical and epidemiological data. Dietary or other pathways must be traced and quantified and causative roles must be identified with regard to target organs or body processes. Moreover, studies must become predictive. Occasionally, simple direct links between geochemistry and health may be identified, but even in these instances confounding factors may be present (for example, the possible role of humic acids in arsenic exposure or the established role of goitrogenic substance in goiter). Ordinarily, geochemistry will provide at best only a risk factor: Unusual exposures, trace element deficiencies, or elemental imbalances will contribute toward the disturbance of cellular processes or activation of genes that will result in clinical disease. The problem of geographical variability in disease incidence will remain.

Rapid growth in the field of medical geology is predicted, as it is a discipline that will continue to make valuable contributions to the study of epidemiology and public health, providing hyperbole is avoided and a dialogue is maintained among geochemists, epidemiologists, clinicians, and veterinarians.

The structure of all living organisms, including humans and animals, is based on major, minor, and trace elements—given by nature and supplied by geology. The occurrence of these gifts in nature, however, is distributed unevenly. The type and quantity of elements vary from location to location—sometimes too much, sometimes too little. It is our privilege and duty to study and gain knowledge about natural conditions (e.g., the bioavailability of elements essential to a healthy life), and the field of medical geology offers us the potential to reveal the secrets of nature.

See Also the Following Chapters. Chapter 10 (Volcanic Emissions and Health) • Chapter 12 (Arsenic in Groundwater and the Environment) • Chapter 13 (Fluoride in Natural Waters) • Chapter 14 (Water Hardness and Health Effects)

• Chapter 15 (Bioavailability of Elements in Soil) • Chapter 16 (Selenium Deficiency and Toxicity in the Environment) • Chapter 17 (Soils and Iodine Deficiency) • Chapter 21 (Animals and Medical Geology) • Chapter 25 (Environmental Pathology) • Chapter 28 (GIS in Human Health Studies) • Chapter 29 (Investigating Vector-Borne and Zoonotic Diseases with Remote Sensing and GIS).

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Geomedical aspects in present and future research (1980)

Geomedical research in relation to geochemical registrations (1984)

Geomedical consequences of chemical composition of freshwater (1987)

Commercial fertilizers and geomedical problems (1987)

Health problems in connection with radiation from radioactive matter in fertilizers, soils, and rocks (1988)

Excess and deficiency of trace elements in relation to human and animal health in Arctic and Subarctic regions (1990)

Human and animal health in relation to circulation processes of selenium and cadmium (1991)

Chemical climatology and geomedical problems (1992)

Geomedical problems related to aluminum, iron, and manganese (1994)

Chemical data as a basis of geomedical investigations (1996)

Some geomedical consequences of nitrogen circulation processes (1997)

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Bölviken B (ed) (2001) Natural ionizing radiation and health. Trondheim, Norway

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Appendix C: Glossary

a-axis a vector direction defined by the space group and crystal structure for a particular crystalline form a term used in crystallography.

absorption the process by which a substance or a xenobiotic is brought into a body (human or animal) or incorporated into the structure of a mineral.

acanthosis increase in thickness of stratum spinosum (specific layer in epidermis/skin).

acid rain contamination of rain by artificial pollutants or natural emissions (such as sulfur dioxide from volcanic activity) which produces an acid composition.

activity the thermodynamically effective concentration of a chemical species or component.

acute myocardial infarction (AMI) gross necrosis of the heart muscle as a result of interruption of the blood supply to the area.

adsorption the binding of a chemical compound to a solid surface.

advection a transport process in which dissolved chemicals move with flowing groundwater.

albedo the percentage of the incoming solar radiation reflected back by different parts of the Earth's surface.

aldosterone a steroid hormone produced by the adrenal gland that participates in the regulation of water balance by causing sodium retention and potassium loss from cells.

aliquot a known amount of a homogeneous material, assumed to be taken with negligible sampling error. When a sample is "aliquoted", or otherwise subdivided, the portions may be called split samples.

alkali disease disease affecting animals that ingest feed with a high selenium concentration, characterized by dullness, lack of vitality, emaciation, rough coat, sloughing of the hooves, erosion of the joints and bones, anemia, lameness, liver cirrhosis, and reduced reproductive performance.

alkalinity the capacity of solutes in a solution to react with and neutralize acid determined by titration with a strong acid to an end point at which virtually all solutes contributing to the alkalinity have reacted. In general the alkalinity in water equates with the bicarbonate concentration.

allergy immunologic state induced in a susceptible subject by an antigen (allergen).

alluvial deposited by rivers.

alteration (Earth science) a process due to high-temperature fluids and gases that occurs within the Earth's crust and results in the formation of new mineral suites that are in equilibrium with their environment. Alteration can also occur at low temperatures.

aluminosilicate a mineral composed dominantly of aluminum, silicon, and oxygen, and lesser amounts of cations such as sodium, potassium, calcium, magnesium, and iron.

amorphous a lack of crystallinity or the regular extended three-dimensional order of the atoms in a solid.

anaerobic/aerobic environmental conditions in which oxygen is absent/present.

analyte any substance whose identity or concentration is being determined.

anemia any of several conditions in which the oxygen-carrying capacity of the blood is below normal due to reductions in the number of red blood cells (hypocytic) and/or the amount of hemoglobin per red blood cell (hypochromic).

aneuploidy cellular state where there is an abnormal number of chromosomes, not a multiple of the haploid number of chromosomes.

aneurysm localized ballooning of the aorta or an artery, potentially causing pressure on adjacent structures and liability to rupture.

angiotensin a vasoconstrictive hormone.

antisense nucleic acid that has a sequence exactly opposite an mRNA molecule made by the body binds to the mRNA molecule to prevent a protein from being made.

apo without, especially metalloproteins without the metal/metals.

apoptosis programmed cell death, in which a cell brings about its own death and lysis, signaled from outside or programmed in its genes, by systematically degrading its own macromolecules.

aqueous speciation the partitioning of chemical components between various aqueous species in a solution: free species (e.g., Ca^{2+}), ion pairs (e.g., $CaCO_3{}^0$), and complexes (e.g., $Fe(CN)_6{}^{3-}$).

aquifer a water-bearing rock formation.

aquitard a rock formation with poor permeability and hence a poor water-bearing unit.

archaea prokaryotes lacking a nucleus as bacteria, but they are as different from bacteria as are humans they represent their own evolutionary pathway they live in extreme places with high temperatures.

arenosols sandy soils with >65% sand-sized (0.05–2 mm) particles these soils have low moisture and low concentrations of most elements and are highly prone to causing deficiencies of micronutrients in crops.

aridisol soils found in arid and semi-arid environments characterized by a light color, poorly developed soil horizons, high soluble salt content, little organic material, and a coarse texture.

arrhythmia irregularity of the heart beat.

arthroconidia fungal spores released by fragmentation or separation of the cells of a hypha.

asbestos a commonly used term for a group of fibrous silicate minerals that includes extremely fibrous serpentine (chrysotile) and the amphibole minerals crocidolite, amosite, tremolite, actinolite, and anthophyllite.

asbestosis degenerative fibrosis of the lung resulting from chronic inhalation of asbestos fibers.

ascariasis an infection caused by the parasitic worm *Ascaris lumbricoides* that is found throughout temperate and tropical regions. Intestinal infection may result in abdominal cramps and obstruction, while passage through the respiratory tract causes symptoms such as coughing and wheezing. In children, migration of the adult worms into the liver, gallbladder, or peritoneal cavity may cause death.

ascidian any minute marine invertebrate animal of the class Ascidiacea, such as the sea squirt.

ash fine particles of pulverized rock ejected from volcanoes.

asphyxiant gas which produces suffocation by replacing oxygen in the respiratory system.

ataxia lack of coordination of muscle for voluntary movement.

atelectasis absence of gas in lung tissue from nonexpansion.

atherosclerosis irregularly distributed intimal deposits of lipid.

atomization the dispersion of fluids into fine particles.

atrium the upper chamber of each half of the heart.

atrophy diminished cellular proliferation.

attribute information about geographic features contained within GIS data layers, or *themes*.

auger effect phenomenon occurring when an electron is released from one of the inner orbiting shells, thereby creating two electron vacancies of the residual atom and repeated as the new vacancies are filled or X-rays are emitted.

autosome a chromosome not involved in sex determination. The diploid human genome consists of 46 chromosomes, 22 pairs of autosomes and 1 pair of sex chromosomes (the X and Y chromosomes).

auxotroph a microorganism possessing a mutation in a gene that affects its ability to synthesize a crucial organic compound.

atypia reactive cellular state, which does not correspond to normal form.

background the property, as applied to a location or measurements from such locations, of being due to natural processes alone and unaffected by anthropogenic processes. In some instances the term natural background is used to reinforce the non-anthropogenic aspect. With the global atmospheric transport of anthropogenic contaminants, e.g., persistent organic pollutants (POPs), it is a moot point whether background sites exist for some substances.

basal cell carcinoma slow growing, locally invasive neoplasm derived from basal cells of epidermis or hair follicles.

baseline a measure of the natural background or ambient level of an element/substance. Some people also suggest that baseline is the current background which could include natural and anthropogenic components.

basolateral membrane part of the plasma membrane that includes the basal end and sides of the cell.

basophilic degeneration pathologic change in tissue noted by blue staining of connective tissue with hema- toxylin-eosin stain.

beneficiation process of concentrating ores.

benign usual or normal the opposite of cancerous when applied to cells or tumors.

bioaccumulation process by which an element is taken into an organism, possibly transformed into another chemical species, and retained so that the element's concentration in the biota is greater than its concentration in the media in which the biota is sustained.

bioapatite the name given to the complex calcium phosphate mineral that forms in biological tissues and is characterized by extremely small crystallite size maximum dimension is typically less that 20×10^{-9} m (200 Å). Generalized chemical formula: $(\mathrm{Ca,Na,Mg,\ldots[\ ]})_{10}\ (\mathrm{PO_4, HPO_4, CO_3, SO_4\ldots})_6(\mathrm{OH, F, Cl, CO_3, O, [\ ]})_2$

where. . .indicates the possible addition of other cations and [ ] indicates vacancies in the crystal structure at the cation or halogen sites.

bioavailability the property of a substance that makes its chemical uptake by biota possible.

bioessential/bioessentiality present in sufficient amounts to support essential biochemical processes imperative for sustaining life.

Biogeochemical cycle model encompassing the movement of elements (and some compounds) from the litho-sphere through the hydrosphere, atmosphere, and biosphere.

biosphere the sum of all organisms on Earth.

birefringence the ability of anisotropic (non-isometric) crystalline materials to split plane polarized light into two non-equal rays of distinct velocities depending on the direction of the transmission relative to the orientation of the atomic structure of the compound. When the two rays emerge from the crystal, one is retarded relative to the other. Precise measurements of the interference colors of the rays define the optical characteristics and identify the compound.

bisphosphonates a group of phosphorus- and carbon-containing compounds that have carbon connected to the phosphorus atom in place of one of the oxygen atoms of the tetrahedral phosphate (PO_4) groups.

blind staggers blind staggers occurs in cattle and sheep ingesting high concentrations of selenium and is characterized by impaired vision leading to blindness, anorexia, weakened legs, paralyzed tongue, labored respiration, abdominal pain, emaciation, and death.

bombs (volcanic) clots of lava that are ejected in a molten or semi-molten state and congeal before striking the ground.

bone a term applied to one of the many individual organs that make up vertebrate skeletons, or alternatively, to the fragments or the tissues that are found within these organs.

Bowen's disease an intraepidermal carcinoma characterized as a small, circumscribed elevation on the skin.

buffer a chemical compound that controls pH by binding to hydrogen ions.

bulk analysis chemical analysis of an entire body/substance of rock or soil or a subpart with little or no segregation of specific areas or components.

c-axis a vector direction defined by the space group and structure of a particular crystalline form. A crystallographic term.

calcisols soils with a high content of free calcium carbonate either developed on limestones, or which have become calcified by the deposition of calcium carbonate in pores and voids as a result of the evaporation of soil solution in arid environments. These soils generally have neutral or alkaline pHs and can adsorb some trace elements very strongly.

calcitonin hormone secreted by the thyroid gland important in the homeostatic regulation of serum calcium levels.

capillary electrophoresis electrophoretic separation technique performed in a small fused silica capillary.

carbon dioxide a colorless odorless gas high concentrations CO_2 acts as an inert asphyxiant in humans.

carbonatite an igneous rock composed of carbonate minerals.

carcinogen a substance that can directly or indirectly cause a cell to become malignant.

carcinogenesis the mechanism by which cancer is caused.

cardiomyopathy disease of the heart muscle (myocardium).

cardiovascular disease (CVD) disease pertaining to the heart and blood vessels, including, for example, both AMI and cerebrovascular disease (stroke).

catecholamines category of compounds including the neurotransmitters adrenaline and noradrenaline.

cation exchange exchange of cations between a solution and a negatively-charged solid phase (e.g., a clay mineral) in response to a change in solution conditions this is especially important in geochemistry for major cations such as calcium and sodium.

cation exchange capacity (CEC) the ability of a soil or soil constituent (e.g., clay mineral or humus) to adsorb cations on permanent, or pH-dependent, negatively charged sites on surfaces. Cations of different elements can replace each other as counter ions to the negative charges.

cDNA complementary DNA: a DNA molecule copied from an mRNA template by the enzyme reverse transcriptase.

cementum the thin tissue that forms the outer covering of a tooth below the gum line, similar in composition to dentine.

chaperones proteins that help in folding proteins correctly and that discourage incorrect folding. Metallochaperones assist in the delivery of metal ions to target proteins or compartments.

chelate the complex formed through the bonding of a metal ion with two or more polar groupings within a single molecule.

chitin a tough white to semi-transparent substance that forms the major structural component of arthropod exoskeletons and the cell walls of certain fungi.

chloroplast chlorophyll-containing photosynthetic organelle in some eurkaryotic cells.

choroid plexus a network of intersecting blood vessels of the cerebral ventricles that regulate intraventricular pressure.

chromatin the complex of DNA and proteins that make up eukaryotic chromosomes.

chromatography the separation of a mixture of compounds using solid, liquid, or gas phases based on affinity of molecules for the phase.

chromosome aberrations any deviation from the normal number or morphology of chromosomes.

clay minerals phyllosilicate minerals with a small grain size, commonly <4 μm but ranging down to colloidal dimensions. When mixed with a limited amount of water they develop plasticity. Clay minerals are formed by high-temperature hydrothermal alteration processes, e.g., kaolinite in altered granitic rocks or by low-temperature weathering processes, e.g., montmorillonite, smectite, chlorite, kaolinite, and illite.

clearance output of particles previously deposited in the respiratory tract.

coccidioidomycosis a respiratory disease of humans and animals caused by inhalation of arthroconidia of the soil-inhabiting fungus *Coccidioides immitis*. Fever, cough, weight loss, and joint pains characterize the disease, also called valley fever.

code (biological) the presentation of the content (of a molecule) in terms of symbols such as ATC and G for the DNA code where ATC and G are nucleotide bases.

codon the fundamental unit of the genetic code consisting of a triplet sequence of nucleotide bases which specifies the ribosomal binding of a specific amino-acid-bearing tRNA during protein synthesis or the termination of that process.

coenzyme a small molecule which binds to a protein to create a catalytic center.

collagen protein making up the white fibers (collagenous fibers) of skin, cartilage, and all connective tissue.

collimator a device for producing a beam of parallel rays.

compartment a separated solution volume of a cell by an enclosing membrane not at equilibrium with any other separated volume.

complex system natural or man-made system composed of many simple nonlinear agents that operate in parallel and interact locally with each other at many different scales. The behavior of the system cannot be directly deduced from the behavior of the component agents and the system sometimes produces behavior at another scale, which is called emergent behavior.

composite a mixture of several components or parts blended together to form a functional whole.

condensation polymer a polymer formed by loss of water molecules from monomers.

confined aquifer aquifer over- and underlain by impermeable or near-impermeable rock strata.

cooling the decrease of the activity of a radioactive material by nuclear decay.

coordination the association of one atom with another in three-dimensional arrays. The coordination number reflects the atomic size of an atom. Octahedral or sixfold coordination is typical of metal atoms with oxygen.

coronary heart disease (CHD) disease caused by deficiency of blood supply to the heart muscle due to obstruction or constriction of the coronary arteries.

cortical the tissue that forms the external portions of bones heavily mineralized with bioapatite-containing cells and exhibiting a variety of textures.

Cretaceous/Tertiary (K/T) boundary the Cretaceous period was the last in the Mesozoic era and was succeeded 64 million years ago by the Tertiary period of the Cenozoic era. It is marked by the sudden extinction of genera of living organisms, most famously the dinosaurs.

crust the outermost solid layer of a planet or moon.

crystallinity the three-dimensional regular array typical of solids with definite chemical composition and crystal structure.

crystalline basement solid igneous, sedimentary, or metamorphic rock may crop out at the ground surface or be overlain by superficial deposits (unconsolidated sediments or soils).

crystallite a general term applied to very small size materials, usually minerals, in which a crystal form or crystal faces may be observed, usually with magnification. The morphology of a crystallite suggests a material with a regular crystal structure and may be used to identify a specific compound or mineral species.

Cytochrome P-450 iron-containing proteins important in cell respiration as catalysts of oxidation-reduction reactions.

cytoplasm the central compartment of all cells that contains genes and DNA as well as synthetic systems.

database a structured set of persistent data, that in a GIS context, contains information about the spatial locations and shapes of geographic features, and their *attributes*.

decay (radioactive) the disintegration of the nucleus of an unstable atom by spontaneous fission or emission of an alpha particle or beta particle.

deconvolution a mathematical procedure used for separation of overlapping peaks.

definitive host the host in which a parasite reaches sexual maturity and reproduces.

dental calculus calcium phosphate mineral materials deposited around the teeth at and below the gumline, probably the result of bacterial action.

dental caries cavities in teeth arising from tooth decay.

dentine the tissue composed of greater than 70% bioapatite that forms the predominant segment of a tooth. This tissue is capped by enamel.

deposition fraction of particles in inspired air that are trapped in the lung and fail to exit with expired air. In geology it is the laying down of sediments.

derivatization the chemical modification of a naturally occurring compound so that it may be more volatile for gas chromatographic separation.

dermis inner aspects of skin that interdigitate with epidermis and contain blood and lymphatic vessels, nerves, glands, and hair follicles.

desorption release of a bound chemical compound from a solid surface (the opposite of adsorption).

detection limit minimum amount of the characteristic property of an element that can be detected with reasonable certainty under specific measuring conditions.

diagenesis changes to the original organic composition of a material caused by low-temperature processes, often involving bacterial action. It can occur in sediments where minerals are altered as well as organic matter. It changes the original chemistry of many minerals and bone when they are buried.

dioxygenase a class of oxidoreductases that catalyze the binding of diatomic oxygen to a product of the reaction.

DOC (dissolved organic compounds, or dissolved organic carbon) the soluble fraction of organic matter in soils and ground and surface waters comprising low molecular weight organic compounds which have the ability to complex many elements and render them more available to plants and more prone to leaching down the soil profile.

dose a general term for the quantity of radiation. The *absorbed dose* is the energy absorbed by a unit mass of tissue whereas the *dose equivalent* takes account of the relative potential for damage to living tissue of the different types of radiation. It is also the quantity of a substance taken in by the body in general.

dose response the relationship between an exposure dose and a measurable biological effect.

dowagers hump the abnormal concave bending of the upper or thoracic spine as a result of osteomalcia or osteoporosis often obvious in older women.

drift (analysis) a slow change in the response of an analytical instrument (geology) it is a superficial sediment.

dry matter (d.m.) remaining solid material after evaporation of all water. Often used to express concentration of minerals and trace elements to eliminate variation due to differences in water content of plant material.

ectodermal relating to ectoderm, the outer layer of cells in the embryo.

eco-district/eco-classification a relatively ecologically homogeneous area of the Earth's surface, an element of a classification based on climatic, biological, pedological, and geological criteria that becomes more specific from eco-zones, through eco-provinces and eco-regions to eco-districts.

effluent the material that is coming from a chromatographic separation. Can also be the waste outfall from industries and is also the term for sewage (sewage effluent).

eggshell calcification a thin calcified layer surrounding an intrathoracic lymph node.

elastosis degenerative changes of collagen fibers with altered staining properties.

electromagnetic spectrum the full range of frequencies, from radio waves to cosmic rays.

electrospray ionization (ESI) ionized molecules by application of a high voltage (approximately 5 kV) to the spray needle.

elimination how xenobiotics are removed from the bloodstream, either by metabolism or excretion.

emissions (volcanic) any liquid, solid, or gaseous material produced by volcanic activity.

enamel the tissue composed of greater than 96% bioapatite that forms the outer surface of teeth.

enantiomer one of two indistinguishable forms of a compound that differ only in the orientation in space a stereoisomer.

endemic Where a disease is confined to specific geographical areas.

endocytosis the process in which the plasma membrane engulfs extracellular material, forming membrane-bound sacs that enter the cytoplasm and thereby move material into the cell.

endosome a small vesicle resulting from the invagination of the plasma membrane transporting components of the surrounding medium deep into the cytoplasm.

endospore an asexual spore formed by some bacteria, algae, and fungi within a cell and released.

endothelium a tissue consisting of a single layer of cells that lines the blood, lymph vessels, heart, and some other cavities.

enterovirus group of viruses transient in the intestine which includes poliovirus, echovirus, and Coxsackievirus.

entisol entisols are soils that formed recently and are often found on floodplains, deltas, or steep slopes where soil development is inhibited. They are weakly developed and lack distinct soil horizons. Entisols have a wide geographic and climatic distribution.

enzootic a disease that affects animals in a specific area, locale, or region.

enzyme proteins that act as catalysts driving plant and animal metabolism.

eosinophils a specific type of white blood cell.

epidemiology the study of the prevalence and spread of disease in a community.

epidermis outer aspect of skin with multiple layers.

eruption (volcanic) the ejection of tephra, gas, lava, or other materials onto the Earth's surface as a result of volcanic or geothermal activity.

erythrocyte a mature red blood cell. Erythrocytes are the major cellular element of the circulating blood, and transport oxygen as their principal function. An increase in the number of cells normally occurs at altitudes greater than 3000 m.

erythron a collective term describing the erythrocytes and their predecessors in the bone marrow.

erythropoiesis the formation of erythrocytes in the bone marrow.

estrogen category of steroid hormones produced by ovarian and adipose tissues that can effect estrus and a number of secondary sexual characteristics and is involved in bone remodeling.

etiological the cause of a disease determined by etiology, the branch of medical science which studies the causes and origins of disease. The etiological agent of coccidioidomycosis is *Coccidioides immitis*.

etiology the process underlying development of a given disease.

eubacteria true bacteria so named to differentiate them from archaea (earlier known as Archaebacteria).

eukaryote cells of organisms of the domain Eukarya (kingdoms Protista, Fungi, Plantae, and Animalia). Eukaryotic cells have genetic material enclosed within a membrane-bound nucleus and contain other membrane-bound organelles.

eutrophication nutrient enrichment of waters that stimulates phytoplankton and plant growth and can lead to deterioration in water quality and ecosystems.

evapotranspiration transfer of water from the soil to the atmosphere by combined evaporation and plant transpiration. It results in a concentration of solutes in the remaining water.

excretion excretion is the mechanism whereby organisms get rid of waste products.

exon a DNA sequence that is ultimately translated into protein.

Exposure response the relationship between how much of a xenobiotic is presented to a person or animal and what happens in their body.

extracellular space in tissue that is outside of cells.

FAO/*Unesco* Soil classification system the soil classification system developed for the joint project by the UN Food and Agriculture Organization and UNESCO to produce the Soil Map of the World (1:5,000,000) published from 1974 onward.

felsic igneous rock rich in feldspar and siliceous minerals (typically light-colored).

ferralsols reddish iron oxide-rich soils characteristic of the tropical weathering and soil-forming environment (humid tropics). These soils generally have a low fertility with low CECs and nutrient contents. Also called oxisols (U. S. Soil Taxonomy), ferralitic, or lateritic soils.

ferritin a soluble protein storage form of iron containing as much as 23% iron.

ferromagnesian a silicate mineral dominated by iron, magnesium, sometimes with aluminum.

fibroblastic cells secretionary cells of connective tissue.

fibroblasts cells that produce collagen molecules.

fibrosis formation of fibrous tissue.

fluorapatite a mineral, ideal formula $Ca_5(PO_4)_3$ F. One of the members of the calcium apatite mineral group.

fluoride F^-, the dominant form of fluorine found in water.

fluorite the dominant fluorine mineral, CaF_2 occurs as an accessory mineral in some sediments and igneous rocks and in some hydrothermal mineral veins.

fluorosis disease affecting bones and teeth, caused at least in part by exposure to high doses of fluoride. Dental fluorosis causes weakening and possible loss of teeth, and skeletal fluorosis causes bone deformation and disability.

fluvial pertaining to rivers and streams.

forestomachs two or three sac-like dilations of the esophagus seen in ruminants and kangaroos. The physiological function of these structures is to serve as fermentation tanks to make cellulose and other carbohydrates in the feed available for absorbtion in the gastrointestinal tract of the animal.

fraction in this context, a term used in sedimentology, pedology, and other physical sciences to describe the mechanical size range of a material.

Fuzzy system a system that uses fuzzy sets and if-then rules to store, compress, and relate many pieces of information and/or data in order to build a model free estimator.

Gamma ray a distinct quantity of electromagnetic energy, without mass or charge, emitted by a radionuclide.

genome the DNA (or for some viruses, RNA) that contains one complete copy of all the genetic information of an organism or virus.

genotoxic the ability of a substance to cause damage to DNA.

geothermal pertaining to the internal heat of the Earth. Geothermal zones are areas of high heat flow, where hot water and/or steam issue at the Earth's surface. They are found close to tectonic plate boundaries or associated with volcanic systems within plates. Heat sources for geothermal systems may be from magmatism, metamorphism, or tectonic movements.

gleys soils under reducing conditions caused by permanent or intermittent waterlogging characterized by pale colors and low concentrations of iron oxides.

gliosis a chronic reactive process in neural tissue.

Glutathione peroxidase a detoxifying enzyme in humans and animals that eliminates hydrogen peroxide and organic peroxides it has a selenocysteine residue in its active site.

glycolysis the energy-yielding metabolic conversion of glucose to lactic acid in muscle and other tissues.

gneiss banded, usually coarse-grained metamorphic rock, having been modified from its original mineralogy and texture by high heat and pressure (high-grade regional metamorphism).

goitrogen a substance which causes or enhances the symptoms of iodine deficiency, e.g., goiter formation.

granite a coarse-grained igneous rock, composed mainly of quartz, alkali, feldspar, and mica. Accessory minerals may also include apatite, zircon, magnetite, and sphene. Granite characteristically has a high proportion of silica ($>70\%$ SiO_2) with high concentrations of sodium and potassium.

granitization a metamorphic process by which sedimentary and metamorphic rocks with a chemistry similar to granites (granitoids) are transformed mineralogically into rocks that look like the granites formed by igneous intrusive processes.

granulomatous inflammation inflammatory reaction where tissue cells of monocyte/macrophage cells predominate.

granulomatous reaction reaction leading to the formation of granuloma, or chronic inflammatory lesions.

grazing feeding behavior of cattle, sheep, and horses consumption of grass and other plants from the ground, mostly rather indiscriminately.

groundwater subsurface water in the zone of saturation in which all pore spaces are filled with liquid water (although sometimes the term groundwater is used inclusively for all water below the land surface, to distinguish it from surface water).

half-life the time in which one-half of the atoms of a particular radioactive substance decay to another nuclear form.

hardness water the content of metallic ions in water, predominantly calcium and magnesium, which react with sodium soaps to produce solid soaps or scummy residue and which react with negative ions to produce scale when heated in boilers.

haversian bone the tissue type found throughout the skeleton in humans that signifies sites of resorption and remodeling. Characterized in cross section by a circular outline and a lamellar distribution of cells and mineralized tissue around a central blood vessel, which is called the haversian canal.

heavy metal a metal with a density more than 4500kgm^{-3}.

helminth a multicellular worm, generally parasitic, often with a complex reproductive system and life cycle. Generally 50–2000 μm in length, but may be longer.

heme the protoporhyrin component of hemoglobin (in erythrocytes) and myoglobin (in myocytes), the proteinaceous chelation complexes with iron that facilitate transport and binding of molecular oxygen to and in cells.

hemolysis lysis of erythrocytes that potentially causes anemia.

hemorrhage profuse bleeding from ruptured blood vessels.

hemosiderin an insoluble iron-protein complex that comprises a storage form of iron mainly in the liver, spleen, and bone marrow.

hepatolenticular hepato, means belonging to the liver lenticular means lens shaped and refers to the basal ganglia of the brain.

herbivores animals normally feeding on plant material such as cattle, horses, sheep, antelope, deer, and elephants, but also rodents like mice, rabbits, and hares. As vertebrates lack enzymes in the gastrointestinal tract that can digest cellulose and other complex carbohydrates present in plants, they utilize microorganisms living in their gastrointestinal tract for this process. See also Ruminants and Large Intestine Fermenters.

hexagonal a description of a specific crystallographic form in which the c-axis is perpendicular to three axes, usually designated as a axes, which are 120 degrees relative to each other. Apatite crystals often show hexagonal prisms with a 60 degree angle measured between adjacent vertical or prism crystal faces.

histology science concerned with the minute structure of cells, tissue, and organs, utilizing light microscopy.

histomorphometry the study of the textures of tissues using sections of samples embedded in paraffin or epoxy. The sections cut from the embedded blocks may be stained to assist in the identification of specific tissue components, i.e., collagen or special components in the nucleus of a cell.

histones the family of five basic proteins that associate tightly with DNA in the chromosomes of eukaryotic DNA.

homeostasis the state of equilibrium in the body with respect to various functions and the chemical compositions of fluids and tissues, including such physiological processes as temperature, heart rate, blood pressure, water content, blood sugar, etc., and the maintenance of this equilibrium.

homeostatic control the ability or tendency of an organism or cell to maintain internal equilibrium by adjusting its physiological processes.

homologue a member of a chromosome pair in diploid organisms or a gene that has the same origin and functions in two or more species. To an organic chemist this is series of compounds that are similar in structure. For instance methanol, ethanol, and the other alcoholsrepresent a homologous series of compounds.

hormone a circulating molecule released by one type of cell or organ to control the activity of another over the long term, e.g., thyroxine.

host a human or animal in which another organism, such as a parasite, bacteria, or virus, lives.

humus the fraction of the soil organic matter produced by secondary synthesis through the action of soil microorganisms it comprises a series of moderately high molecular weight compounds that have a high adsorptive capacity for many metal ions.

Hydraulic conductivity the volume of water that will move in unit time under a unit hydraulic gradient through a unit cross-sectional area normal to the direction of flow.

Hydraulic gradient the change in static head (elevation head + pressure head) per unit distance in a given direction. It represents the driving force for flow under Darcy's law.

hydrodynamic dispersion the irreversible spreading of a solute caused by diffusion and mechanical dispersion (which, in turn, is caused by indeterminate advective transport related to variations in velocity about the mean).

hydroxylapatite name of the mineral, ideal chemical formula $Ca_5(PO_4)_3(OH)$, one of the members of the calcium apatite mineral group. Hydroxylapatite occurs naturally throughout the different types of rocks on the surface of the Earth and closely resembles the mineral deposits in normal and pathological tissues. See also Bioapatite.

hyperchromatic excessive dark staining.

hyperkeratosis hyperplasia of the stratum corneum (specific layer in epidermis/skin), the outermost layer in the epidermis.

hyperplasia an increase in the number of cells in tissue or an organ.

hypertension high blood pressure.

hyphae the branching threadlike filaments, generally 2–10 μm across, characteristic of the vegetative stage of most fungi.

hyphenated techniques generally, two analytical methods connected in series, e.g., a chromatographic technique directly connected to a spectroscopic technique.

hypoxia less than the physiologically normal amount of oxygen in organs/tissues.

idiopathic describing a disease of unknown cause.

igneous rocks formed from the cooling and solidification of molten rock originating from below the Earth's surface, includes volcanic rocks.

incidence quantifies the number of new cases/events that develop in a population at risk during a specified time interval.

inductively coupled plasma (ICP) an argon plasma with a temperature of approximately 7000–10,000 K, produced by coupling inductively electrical power to an Ar stream with a high-frequency generator (transmitter). Then plasma is used as an emission source (atomic emission spectrometry) or as an ionization source (mass spectrometry).

inselberg an isolated peak of hard rocks that has stubbornly resisted erosion most commonly found in the tropics.

integrin a membrane protein that conveys information in both directions across the plasma membrane.

internal dose amount of an agent penetrating the absorption barriers via physical or biological processes.

iodothyronine deiodinase selenoproteins responsible for the production and regulation of the active thyroid hormone from thyroxine.

ischemia ischemia occurs due to the disruption of the supply of blood and oxygen to organs and cells.

isoform the descriptor for a specific form of a protein that exists in multiple molecular forms also, for enzymes, isozyme.

isotachophoresis separation mode in capillary electrophoresis, separating according to analyte conductivity.

isotope one of two or more atoms with the same atomic number but with different atomic weights.

Kashin-Beck disease an endemic osteoarthropathy (stunting of feet and hands) causing deformity of the affected joints occurs in Siberia, China, and North Korea.

keratinocytes cells of the epidermis that produce the protein keratin.

Keshan disease an endemic cardiomyopathy (heart disease) that mainly affects children and women of childbearing age in China.

kinase an enzyme catalyzing the conversion of a proenzyme, or zymogen, to its metabolically active form, frequently via phosphorylation or proteolytic cleavage.

K_m the Michaelis constant in enzyme kinetics.

lahar a hot or cold flow of water-saturated volcanic debris flowing down a volcanic slope.

lamellar bone the tissue that shows sequential layers of mineralized matrix, cells, and the blood system required to maintain its viability. This tissue probably represents a second stage after the initial deposition of woven bone.

large intestine fermenters different animal species utilizing bacteria and protozoa in their large intestine (cecum or colon) to digest cellulose and starch in plants eaten so the nutrients can be absorbed in the gut of the animal. Horses, donkeys, zebras, rabbits, and hares are examples of animal species utilizing large intestine fermentation to facilitate digestion.

lattice an array with nodes repeating in a regular three-dimensional pattern. A crystal lattice is the array distinctive for the chemical and physical structure of the crystalline compound.

lava magma which erupts onto the Earth's surface lava may be emitted explosively, as lava fountains, or by oozing from the vent as lava flows.

leachate a liquid that carries dissolved compounds from a material through which it has percolated (e.g., water which carries adsorbed elements from settled volcanic ash into soil or water).

Lewis acid a chemical center which accepts electron pair donation from a donor base, e.g., M^{2+} is a Lewis acid in the complex $M^{2+} \underline{\leftarrow} OH_2$.

Lewy bodies intracytoplasmic inclusion seen in Parkinson's disease.

lichenoid accentuation of normal skin markings.

ligand a binding unit attached to a central metal ion.

limestone a sedimentary rock composed of calcium carbonate.

lithosphere the solid Earth.

lOAEL the lowest dose at which adverse effects are observed to occur in an experimental setting.

loess natural sedimentary formation made up of wind-lain mineral dust, mainly in the silt size range (1–60 μm), most of which accumulated, often in great thickness, during the Quaternary (the last about 2.6 million years).

lumen a cavity of passage in a tubular organ the lumen of the intestine.

lymph nodes small nodes along the bronchi that drain the tissues of lymph fluid.

lymphatic vascular channel that transports lymph, a clear fluid with predominantly lymphocytes.

lysis destruction of a cell's plasma membrane or of a bacterial cell wall, releasing the cellular contents and killing the cell.

macronutrient general term for dietary essential nutrients required in relatively large quantities (hundreds of milligrams to multiple grams) per day includes energy (calories), protein, calcium, phosphorus, magnesium, sodium, potassium, and chloride.

macrophage mononuclear phagocytes (large leukocytes) that travel in the blood and can leave the bloodstream and enter tissues protecting the body by digesting debris and foreign cells.

magma any hot mobile material within the Earth that has the capacity to move into or through the crust.

marine black shales sedimentary rocks formed from organic-rich muds which have developed under strongly reducing conditions and are generally enriched in a wide range of trace elements.

matrix the basis or collection of materials within which other materials develop. The organic matrix is the base in which mineral materials are deposited to form bone.

matrix effect the combined effect of all components of the sample other than analyte on the measurement of quantity.

melanin dark pigment that provides color to hair, skin, and the choroid of the eye.

mesothelioma a highly malignant type of cancer, usually arising from the pleura, which is the lining of the thoracic cavity, and characteristically associated with exposure to asbestos.

messenger (transmitter) a molecule or ion used to convey information rapidly in or between cells, e.g., Ca^{2+}.

metabolism the enzymatic chemical alteration of a substance. In toxicology, how xenobiotics are converted chemically in life sciences generally, the pathways of chemical reactions that occur in the body.

metabolome the small organic molecule composition in concentration units of a cell or compartment.

metadata data about data, typically containing information such as time and place of database creation, *field* and *record* identifier information (attributes), data development process, map projection, and person to contact regarding the database also known as data dictionary.

metalliferous rich in metals.

metalloid an element which behaves partly as a metal and partly as a non-metal, sometimes referred to as a "semi-metal."

metallome the element composition in concentration units of a whole or a part of a cell where the element may be in free or combined form.

metamorphic rocks rock formed from the alteration of existing rock material due to heat and/or pressure.

micellar electrokinetic chromatography separation mode in capillary electrophoresis, separating according to the ability of apolar analytes to enter the (apolar) core of surface charged micelles.

micronutrient general term for dietary essential nutrients required in relatively small amounts (less than multiple milligrams) per day includes the vitamins and trace elements.

microradiograph a picture produced using X-rays or rays from a radioactive source showing the minute internal textures of a planar thin section of a mineralized tissue sample.

mineral a naturally occurring compound with definite chemical composition and crystal structure, of which there exist over 4000 officially defined species.

mineral elements equal to elements. This term is used by nutritionists.

mineral group an aggregate of mineral species that shares structural and chemical affinities.

mineral nutrient a metal, non-metal, or radical that is needed for proper body function and maintenance of health also used in reference to plant nutrition.

mineralization the presence of ore and non-ore (gangue) minerals in host rocks, concentrated as veins, or as replacements of existing minerals or disseminated occurrences typically gives rise to rocks with high concentrations of some of the rarer elements.

mitochondrion subcellular organelle containing the electron transport chain of cytochromes and the enzymes of the tricarboxylic acid cycle and fatty acid oxidation and oxidative phosphorylation, thus, constituting the cell's primary source of energy.

mitogenic a factor that causes mitosis of cells.

mitosis the division of a cell into two daughters with identical complements of the nucleic material (chromosomes) characteristic of the species.

model a conceptual, physical, or mathematical representation of a real system or process.

monoclinic the description of a special crystallographic form for the structure of a compound in which the three axes are not mutually perpendicular.

monooxygenase a class of oxidoreductases that catalyze the dissociation of molecular (diatomic) oxygen such that single oxygen atoms are bound to different products of the reaction.

mT metallothionein.

mucosal cell cell of the mucous membranes of the gastrointestinal tract.

multichannel analyzer (MCA) an instrument that collects, stores, and analyzes time- or energy-correlated events.

multistage carcinogenesis model a mathematical model that assumes a sequential series of DNA-damaging events is necessary for a single cell to become malignant. The model also assumes linearity at low doses.

mycelium the vegetative part of a fungus (or in some cases bacteria), consisting of a mass of branching, threadlike hyphae.

mycorrhizae symbiotic fungi which colonize the outer layers of the roots of many plant species and whose external mycelium effectively increases the effective absorptive surface area of the roots.

myocyte a muscle cell.

myxedematous cretinism form of mental retardation caused by perinatal iodine deficiency.

natural background a term used to describe the geochemical variability and the range of data values due to natural processes, that characterize a particular geological or geochemical occurrence. See also Background and Baseline.

nebulizer interface at plasma detectors for aerosol production.

necrosis cell death.

nephrotoxin cytotoxin specific for cells of kidney.

neurotransmitter any of several compounds released by neurons to stimulate other neurons.

neutrophil a specific type of white blood cell.

nOAEL the highest dose at which no observed adverse effects occur in an experimental setting.

nuclide a general term applied to any atom with data on the number of protons and neutrons in its nucleus.

odds probability of disease divided by probability of no disease (p/1-p) within a study group (e.g., exposed individuals).

odds-ratio ratio between odds for exposed and odds for non-exposed ($\text{odds}_{+\text{exp}}/\text{odds}_{-\text{exp}}$).

oligonucleotide a DNA polymer composed of only a few nucleotides.

omnivores animals normally feeding on both plant and animal material. Species considered omnivores are humans, dogs, and swine.

oncogene a gene that controls growth and when aberrant or when activated inappropriately may permit cancer to develop.

operon a cluster of genes with related functions that are under the control of a single operator and promoter, thereby allowing transcription of these genes to be turned on and off.

organ systems part of body performing a specific function.

organelle a compartment found in eukaryotes derived from captured bacteria and with residual independent genes, e.g., *mitochondria* which create useful energy from oxidation of sugars and *chloroplasts* which create useful energy from light-generating oxygen.

organization a managed flow of material and energy in contrast with static order.

orthogonal (analytical) speciation concept analytical strategies which employ combinations of various separation and/or detection methods are called orthogonal analytical concepts.

ortholog a gene in two or more species that has evolved from a common ancestor.

osteoblasts a bone-forming cell function with bone-removing cells (osteoclasts) in the normal process of bone remodeling.

osteoclasts multinucleate cells that destroy bone tissue.

osteomalacia impaired mineralization of bone tissues resulting in areas where mineral is missing. One possible cause of osteomalacia is a deficiency of vitamin D, the hormone required for adequate calcium absorption and deposition as bioapatite in bone tissues.

osteon the bulls-eye pattern of concentric rings of lamellar bone around a vascular canal. This structure is detected in tissue sections that form as a result of bone tissue remodeling. See Haversian Bone.

osteoporosis a generalized term for the loss of bone tissues in bone organs. There are multiple possible causes of osteoporosis and the loss may occur at any age, but it is more prevalent in older individuals. The variations of osteoporosis remain active areas for investigation.

osteosclerosis disease characterized by abnormal hardening of bone due to excessive calcification.

oxalic acid a dicarboxylic acid (ethane dioic acid, $C_2H_2O_4$) found in some plants and produced by molds forms stable chelation complexes with divalent cations (Ca^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+}, Cu^{2+}) rendering them unavailable from the diet.

oxidation chemical process which can lead to the fixation of oxygen or the loss of hydrogen, or the loss of electrons the opposite of reduction.

oxidoreductase an enzyme that catalyzes an oxidation-reduction reaction.

p*53* gene a tumor-suppressor gene that codes for a transcription factor involved in preventing genetically damaged cells from proliferating.

Paget's disease a disorder in which the normal resorption and sculpting of bone is compromised and superfluous or more dense mineralized tissue is deposited.

parakeratosis retention of nuclei in the cells of the stratum corneum.

parasitimia the condition of having parasites within the bloodstream. Usually the parasite is a protozoan.

parathyroid hormone hormone secreted by the parathyroid gland important in the homeostatic regulation of serum calcium levels.

parent material the weathered rock material on which a soil is formed. Can be either fragments of the underlying solid geology or transported drift material overlying the solid geology.

parenteral administration of substance into organism not through gastrointestinal tract but through intramuscular, subcutaneous, or intravenous injection.

parkinsonism clinical syndrome characterized by diminished facial expression, slowness of voluntary movement, rigidity, tremor, and stooped posture.

pedogenesis the process of soil formation involving various physical and chemical processes which give rise to the formation of a soil profile. The nature of soil formed is determined by the interactions of the climate, vegetation, parent material, topography, and time.

periodic table a tabular classification of the chemical elements whereby they are organized into (vertical) groups based on progessive increases in numbers of electron shells surrounding the atomic nucleus and (horizontal) rows based on changes in the internal complexities of the electron shells. Elements within any group have similar chemical properties.

periplasm a secondary enclosed compartment of a prokaryote outside the cytoplasm and surrounding it.

permafrost permanently ice-bearing frozen ground, found in the Arctic, Antarctic, and some high-altitude regions.

pH a measure of the acidic (or alkaline) nature of an aqueous solution, expressed as the negative base -10 logarithm of the activity of protons in the solution. Solutions with pH values below 7 are considered acidic values greater than 7 indicate basic (or alkaline) conditions.

phagocytosis a type of endocytosis in which extensions of a plasma membrane engulf extracellular particles and transport them into the interior of the cell.

pharmacognosy the study of the useful drug effects of natural products.

phase a volume of space, solid, liquid, or gas in equilibrium with other volumes and described by a boundary. A homogeneous, distinct portion of a chemical system.

phase diagram a graphical representation of the stability relationships between phases in a chemical/physical system usually representing states at equilibrium. The presentation usually depicts relationships based on changes in composition, temperature, or pressure.

phenotype the physical characteristics of an organism that can be defined as outward appearance (such as flower color), as behavior, or in molecular terms (such as glycoproteins on red blood cells).

phosphorite a sedimentary rock with a high percentage of phosphate materials, shell, or bone fragments that may be mined for use as fertilizer. Prominent textural features are often nodules and pellets of extremely fine-grained calcium phosphate.

photoelectron electron that is ejected from the surface when light falls on it.

phyllosilicate a group of aluminosilicate minerals that have a sheeted crystal structure which permits cations to be trapped between the sheets and around the sheet edges. Because of these properties some are capable of sequestering geochemically significant amounts of cations, metals.

phytic acid inositolhexaphosphoric acid ($C_6H_6O_6[H_2PO_3]_6$) found in plants forms stable chelation complexes with divalent cations (Ca^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+}, Cu^{2+}) rendering them unavailable from the diet.

phytoavailability a specific instance of bioavailability with reference to plants. In some instances it is useful to differentiate between phyto- and bioavailability along the food chain. Phytoavailability controls the transfer of a trace element from soil to a plant, and bioavailabilty controls the transfer of the trace element from the plant material to the receptor organism the transfer factors are unlikely to be the same.

phytosiderophores organic compounds released by the roots of some plants suffering from a deficiency of iron or certain other micronutrients. They mobilize iron and elements co-precipitated onto iron oxides and render them available for uptake by the plant.

phytotoxic toxic to plants.

pica a craving for unnatural articles of food. The name pica comes from the Latin for magpie, a bird that picks up a variety of things either to satisfy hunger or out of curiosity. Geophagy, the deliberate ingestion of soil, is a form of pica.

Placer deposits alluvial deposits which contain ore minerals (commonly native gold, platinum, diamond, cassiterite) in economic quantities these are heavy minerals which are concentrated by reworking of primary ore bodies. They typically concentrate in low-energy environments such as floodplains and deltas. Many important placer deposits occur also as beach placers where they have been concentrated by seawater movement.

platelet a non-nucleated, hemoglobin-free cellular component of blood that functions in clotting also called a thrombocyte.

platform a term used in geology to describe a large stable section of the Earth's crust that is unaffected by current mountain building. Commonly formed over long periods of time by the erosion of the Earth's surface to relatively low relief.

plaque the unwanted deposition of mineral materials in tissue areas such as in the vascular system or around teeth within the gum tissues.

pleiotropy a situation in which a single gene influences more than one phenotypic characteristic.

pleural plaques a fibrous thickening of the parietal pleura which is characteristically caused by inhalation of the fibers of asbestiform minerals.

pM standard: the PM (particulate matter) standard is based on the total mass of particles measuring 2.5 μm or less observed in a 24-h period.

pneumoconiosis a chronic fibrosing lung disease from contact with respirable mineral dusts examples include silicosis and asbestosis.

podsol a type of soil which can be found in cool, humid environments on freely drained parent materials usually under coniferous trees or ericaceous vegetation. Typically has an iron pan as a result of leaching. Also called spodosols in the USDA Soil Taxonomy classification.

polymorph a term applied in mineralogy to describe minerals with the same composition that can crystalize in multiple crystallographic forms. Possibly the most well-known polymorphic minerals are calcite and aragonite both have the chemical composition $CaCO_3$.

primary term used to describe position in the biogeochemical cycle refers to bedrock.

primitive cell a cell thought to have existed some 3–4 billion years ago, although a related form can be found in extreme anaerobic conditions today.

prions an infectious microscopic protein that lacks nucleic acid thought to be responsible for degenerative diseases of the nervous system called transmissible spongiform encephalopathies (TSE) transmissible within and between species.

progesterone the steroid hormone produced by the corpus luteum, adrenal cortex, and placenta that prepares the uterus for reception and development of the fertilized ovum.

progestins a general term for the natural or synthetic progestinal agents.

prokaryote cells of the domains Bacteria or Archaea. Prokaryotic cells have genetic material that is not enclosed in a membrane-bound nucleus they lack other membrane-bound organelles.

proteome the full complement of proteins produced (expressed) by a particular genome.

protista eukaryotic one-celled living organisms distinct from multicellular plants and animals: protozoa, slime molds, and eukaryotic algae.

protozoa comprise flagellates, ciliates, sporozoans, amoebas, and foraminifers.

pulmonary alveoli out-pouchings on the fine lung passages in which oxygen exchange between the alveoli and the bloodstream occurs.

pump (in the context of organisms) a mechanical protein-based device in a cell membrane for transferring material from one compartment to another.

Purkinje cells large nerve cells found in the cerebellum, a large portion of the posterior aspect of the brain.

pyrite iron sulfide (FeS_2), otherwise known as fool's gold occurs commonly in zones of ore mineralization and in sediments under strongly reducing conditions.

pyroclastic flow a fast-moving heated cloud of gas and volcanic particles produced by explosive eruptions or volcanic dome collapse.

Quaternary the most recent period of geological time, spanning 0–2 million years before Present divided into the earliest period, the Pleistocene (ending with the last glacial maximum), and the subsequent Holocene (the last 13,000 years).

quaternary structure the three-dimensional structure of a multisubunit protein particularly the manner in which the subunits fit together.

radioactivity atoms (known as radionuclides) which are unstable and will change naturally into atoms of another element accompanied by the emission of ionizing radiation. The change is called radioactive decay.

radionuclide a radioactive nuclide.

radon a colorless radioactive element comprises the isotope radon-222, a decay product of radium. ^{222}Rn (radon) is a gas. It occurs in the uranium-238 decay series and provides about 50% of the total radiation dose to the average person.

radon potential map a map showing the distribution of radon prone areas delineated by arbitrary grid squares, administrative or geological boundaries. The radon potential classification may be based on radon measurements in existing dwellings, measurements of radon in soil gas, or proxy indicators such as airborne radiometric measurements.

raman microprobe vibrational spectroscopic technique where light scatter allows for characteristic spectra of materials to be obtained.

raster a model of spatial data using an x,y coordinate system, rows and columns, and representing features as cells, or pixels, within.

reactive oxygen species general descriptor for the superoxide (O_2), singlet oxygen (O), and hydrogen peroxide (H_2O_2), each of which has a much greater chemical reactivity with intracellular nucleophiles (proteins, DNA) than molecular oxygen from which it is derived metabolically.

recessive a mode of inheritance in which a gene must be present from both parents for the trait to become manifest in an offspring.

recharge process by which water is added from the atmosphere or ground surface to the saturated zone of an aquifer, either directly into the aquifer, or via another formation.

record a unique entity, commonly in GIS a location, that possesses different values for its attributes in fields.

redox potential (pe or Eh) pe and Eh are related variables that express a measure of the ratio of the aqueous activity of an oxidized species (an electron acceptor, such as Fe^{3+}) to that of a reduced species (an electron donor, such as Fe^{2+}). The redox potential of a solution can provide a sense of the oxidizing or reducing nature of a solution or aqueous environment (oxic, suboxic, sulfidic, methanic).

redox reactions coupled chemical oxidation and reduction reactions involving the exchange of electrons many elements have changeable redox states in groundwater the most important redox reactions involve the oxidation or reduction of iron and manganese, introduction or consumption of nitrogen compounds (including nitrate), introduction or consumption of oxygen (including dissolved oxygen), and consumption of organic carbon.

reducing condition anaerobic condition, formed where nearly all of the oxygen has been consumed by reactions such as oxidation of organic matter or of sulfide reducing conditions commonly occur in confined aquifers.

reduction chemical process leading to the loss of oxygen or increase of electrons by a compound the opposite of oxidation.

reference nutrient intake (RNI) the daily dietary value of a nutrient above which the amount will almost certainly be adequate for everybody.

regolith a deposit of physically and/or chemically weathered rock material which has not developed into a soil due to the absence of biological activity and the presence of organic matter.

reitfield refinement a method of calculating the three-dimensional structure of compounds.

relational database database where data are organized according to the relationships between entities.

relative risk (RR) a risk is the number of occurrences out of the total. Relative risk is the risk given one condition versus the risk given another condition used in epidemiology.

repair (DNA) the action of biological machinery to fix damage, especially referring to maintenance of DNA integrity.

reservoir (biological) a host, carrier, or medium (such as soil), that harbors a pathogenic organism, without injury to itself in the case of carriers, and can directly or indirectly transmit that pathogen to individuals.

residence time period during which water, solutes, or particles remain within an aquifer or organisms as a component part of the hydrological cycle.

respiratory distress impairment of lung function, often resulting in uncomfortable respiratory symptoms, lowered oxygenation and/or elevated carbon dioxide levels in the blood.

retention time elution time of a compound in a chromatographic system depending on its interaction at the stationary phase.

rheumatoid indefinite term applied to conditions with symptoms related to the musculoskeletal system.

rhizosphere the zone around plant roots (2 mm thick) in which there is intense microbial activity due to root exudates and which has chemical properties different from the bulk of the soil.

ribozyme rNA molecule with catalytic activity.

rickets disease of children characterized by under-mineralization of growing bone, leading to physical deformities of the weight-bearing bones most notably of the legs, wrists, and arms.

risk assessment a systematic way of estimating the probability of an adverse outcome based on the known properties of a hazard such as a chemical.

ruminants several groups of animal species utilizing bacteria, fungi, and protozoa in their forestomachs to digest cellulose and starch in plants eaten so the nutrients can be absorbed in the gut of the animal. Cattle, sheep, goats, antelope, deer, and camels are examples of ruminants.

saline intrusion phenomenon occurring when a body of salt water invades a body of fresh water it can occur either in surface water or groundwater bodies.

saprophyte an organism, often a fungus or bacterium, that obtains its nourishment from dead or decaying organic matter.

saprozoonoses zoonotic diseases where transmission requires a non-animal development site or reservoir. Soil can often serve as the reservoir.

sarcoidosis a systemic granulomatous disease of unknown cause.

sarcomatoid resembling a sarcoma, a neoplasm of soft tissue.

scanning electron microscope (SEM) a method employing an electron microscope and a finely-focused beam of electrons that is moved across a sample allowing the surficial textures to be examined at high resolution and the image displayed. By collecting the emitted electrons from a single spot (size 1–10 μm) chemical analysis of portions of the sample, i.e., a specific mineral species, can be made using energy dispersive X-ray analysis (SEM/EDXA).

screw axis a specific translational and rotational characteristic of a lattice direction (axis) defined as part of one of the known 230 space groups. The calcium apatite group has a screw axis designated as 6_3. The c-axis has sixfold-symmetry with a screw. The screw rotates 120 degrees around the sixfold-axis with each one-third translation along the axis, part of the space group designation of the apatite unit cell.

secondary terms used to describe position in the biogeochemical cycle refers to weathering products and processes resulting from, or acting on, primary rock material.

sedimentary rock rock formed by compression of material derived from the weathering or deposition of pre-existing rock fragments, marine or other organic debris, or by chemical precipitation.

selenocysteine an unusual amino acid of proteins, the selenium analog of cysteine, in which a selenium atom replaces sulfur.

selenomethionine 2-amino-4-(methylseleno) butanoic acid.

selenosis selenium toxicity.

sesquioxide oxide mineral containing three atoms of oxygen and two atoms of another chemical substance. Iron and aluminum oxides are the most important in the natural environment.

shale a sedimentary rock composed of fine particles, mainly made up of clay.

silicate a mineral composed dominantly of silicon and oxygen, with or without other elements such as magnesium, iron, calcium, sodium, and potassium.

silicosis a form of pneumoconiosis produced by inhalation of fine silica particles.

smectite a group of clay minerals (phyllosilicates) that includes montmorillonite and minerals of similar chemical composition. They possess high cation exchange capacities, and are therefore capable of sequestering labile cations.

soil profile (solum) the vertical section of a soil from the surface to its underlying parent material. It comprises distinct layers (horizons) differing in appearance or texture and chemical properties. The soil profile is the basis of soil classification (soils with characteristic combinations of horizons).

soil texture the relative proportions of sand (0.05–2 mm), silt (0.002–0.05 mm), and clay (<0.002 mm) sized particles in a soil which affects both its physical and chemical properties.

solubility equilibrium concentration of a solute in water at a given temperature and pressure when the dissolving solid is in contact with the solution.

sorption the retention of ions on solid surfaces in the soil by a combination of mechanisms**:** ion exchange, specific adsorption, precipitation, and organic complexation.

space group a mathematical expression that uniquely defines the three-dimensional array typical of a crystalline material.

spallation splitting off, particularly applied to splitting off parts of the nucleus of an atom, resulting in the formation of a different element.

spherule a small spherical structure of the invasive phase of *Coccidioides immitis* that fills with endospores as it matures. The spherule ruptures at maturity releasing the infective endospores into the host.

spongiosis intercellular edema of epidermis.

spray chamber (chemical analysis) part of sample introduction system, connected to a nebulizer. Droplets from the aerosol that are too big are discarded.

squamous cell carcinoma malignant neoplasm derived from stratified squamous epithelium.

stable isotope isotope that does not undergo radioactive decay.

standardized mortality ratios a statistical method for comparing the mortalities of different population groups by separating data according to sex and then age band.

steatosis general term describing fatty degeneration t-RNA**:** transfer ribonucleic acid any of a number of such intracellular factors involved in protein synthesis by transferring in sequence individual amino acids to the ribosome.

stereoisomer one of two forms of a compound that is indistinguishable from the other outside of the orientation in space. An enantiomer.

stoichiometric a term applied when a phase or compound has the charge balance and chemical proportions expected in the ideal formula.

swayback neonatal ataxia, a clinical manifestation of copper deficiency in lambs. The condition is characterized by incoordination of movement and high mortality. The disease is known as lamkrius in South Africa, kipsiepsiep in Kenya, and enzootic ataxia in several other countries, including the former Soviet Union.

symbiosis the cohabiting of more than one organism which supply one another with vital material and energy.

synergy a positive interaction.

tachycardia rapid heart beat.

tachypnea rapid breathing.

tephra any solid material produced and made airborne by volcanic activity (including bombs, blocks, ash, and dust).

termite mounds a common source of geophagical material in the tropics. The edible part of a termite mound is the extremely mineraliferous, soft, protected interior comprising the queen's chamber, nursing galleries, and fungus gardens.

tetrahedral orthophosphate group the three-dimensional atomic array in which four oxygen atoms are distributed at the apices of the tetrahedron around the phosphorus atom.

theme (GIS) a GIS data layer, or coverage used in an overlay analysis with spatial referencing.

threshold in biology it is a dose level, below which, no adverse effect is expected. In Earth science it represents the upper or lower limit of background—above or below which is anomalous.

thylakoid a disk-shaped, membranous sac found in chloroplasts, the membranes of which contain the photosystems and ATP-synthesizing enzymes used in the light-dependent reactions of photosynthesis.

thyroxine also referred to as $3:5,3':5'$ tetra-iodothyronine (T_4) is the major hormone secreted by the thyroid gland. T_4 is involved in controlling the rate of met-abolic processes in the body and influencing physical development.

TNF tumor necrosis factor.

tomography a method employing transmission X-radiological analysis to visualize the bones or bony portions of the skeleton. The X-ray source moves relative to the patient.

tonsillar herniation physical displacement of cerebellar tonsil into foramen magnum, a large opening at base of the brain.

toxicity state of being poisonous and disturbing organ function.

toxicodynamics the mechanisms by which xenobiotics induce their effects in the body the mechanisms of the toxic response.

toxicokinetics the mechanisms by which xenobiotics are handled in the body, comprising the steps *absorption*, *distribution*, *metabolism*, and *excretion*.

toxicology originally, the study of poisons and now the general science of the handling by, and response of, the body to xenobiotics and the patterns of adverse effects that result.

toxocariasis also called visceral larva migrans (VLM), toxocariasis is caused through infection with the larvae of *Toxocara canis* or *T. cati* (the common roundworm of dogs and cats, respectively). After infection, the eggs hatch into larvae and are carried into the circulation and to various tissues. Respiratory symptoms develop, and there is a swelling of body organs such as the liver. A complication of VLM is epilepsy and ocular larva migrans, the latter caused by microscopic worms entering the eye.

toxoplasmosis a disease attributable to the ingestion of *Toxoplasma gondii*, one of the most common human parasites that infect 30–60% of the global population. Commonly caused by eating of undercooked meat with soil ingestion as secondary source. Recent research has suggested that human behavior can be adversely affected following *T. gondii* infection.

Trace elements (in medicine) general term for the nutritionally essential mineral elements that are required at levels of intake less than about $50 \mathrm{mgd}^{-1}$ includes iron, copper, zinc, iodine, selenium, manganese, molybdenum, chromium, fluoride, and cobalt.

transcription the act of producing RNA from DNA leading to *translation*, protein production.

transfection the uptake and expression of a foreign DNA sequence by cultured eukaryotic cells or the introduction of foreign DNA into a host cell.

transposon a segment of DNA that can become integrated at many different sites along a chromosome (especially a segment of bacterial DNA that can be translocated as a whole).

trichiuriasis infestation with the roundworm *Trichuris trichiura* that may cause nausea, abdominal pain, diarrhea, and occasionally anemia and rectal prolapse.

triiodothyronine also referred to as 35,3′ triiodothyronine (T_3) produced in the thyroid gland and involved in controlling the rate of metabolic processes in the body and physical development.

trabecular the porous tissues forming the internal sectors of bones. The trabeculae are bone tissue spicules. This type of tissue is often adjacent to the hollow core or within the marrow cavity.

transmissible spongiform encephalopathies (TSE) rare forms of progressively degenerative diseases of the nervous system that affect both humans and animals. They are caused by agents called prions and generally produce spongiform changes in the brain. Examples include chronic wasting disease (CWD) in deer and elk, bovine spongiform encephalopathy (BSE) in cattle, and Creutzfeldt-Jakob disease (CJD) in humans.

type 1 collagen the special variety of the collagen molecule typically found in the matrix of tissues that will become mineralized as bone.

ultramafic rock igneous rock composed substantially of ferromagnesian silicate minerals and metallic oxides and sulfides, with $<45\%$ silica, and almost no quartz or feldspar.

ultrastructure morphometry of particles and cell structure based on electron microscopy.

unconfined aquifer aquifer containing unconfined groundwater, i.e., having a water table and an unsaturated zone.

unit cell the smallest geometric volume that uniquely defines the composition and precise structure of a crystalline compound. The basis for the repetitive pattern that completely characterizes a compound, its chemistry, and three-dimensional arrangements of all the constituent atoms.

USDA Soil Taxonomy the soil classification system devised by the United States Department of Agriculture (published in 1975).

vasodilation expansion of the blood vessels.

vadose zone also known as the "unsaturated zone" is the part of the Earth's surface extending down to the water table.

vector (GIS) model of spatial data using points, lines, and polygons to represent geospatial features and boundaries. Vector in the entomological sense, is typically an arthropod that transmits disease-causing pathogens to humans.

vector-borne disease disease that is transmitted from one vertebrate host to another by an invertebrate, usually an insect, tick, or snail.

viremia the existence of virus or viral particles in the bloodstream.

virulence the capacity of a microorganism for causing disease.

$\mathbf{v_{max}}$ the maximum velocity (never attained) in enzyme kinetics.

volatile fatty acids (VFA) common name for acetic acid, butyric acid, and propionic acid normally formed under anaerobic conditions in the forestomachs and large intestine of herbivores. After absorption from the gastrointestinal tract, VFA can be further metabolized and used mainly for energy production. In ruminants, VFAs are the dominating energy source equivalent to glucose in the metabolism of other species.

volcanic gas gas produced by volcanic activity or geothermal processes. Steam is the most common gas those of relevance to health include the inert asphyxiants, irritant gases, or noxious asphyxiants.

volcanic monitoring geological and epidemiological testing and surveillance prior to, surrounding, and subsequent to an eruptive event or degassing episode includes the period of post-disaster recovery and rehabilitation.

volcano an opening in the crust from which gases, lava, and/or tephra are expelled.

voltammetry an electrochemical determination method based on the characteristic redox potential of the measured compound.

weathering a process at or near the Earth's surface caused by the interaction of water, oxygen, carbon dioxide, and organic acids with the minerals present includes hydrolysis and oxidation reactions. Weathering can result in the formation of new mineral suites that are in equilibrium with their environment. In Arctic and high mountainous regions chemical weathering may be limited, and weathering is largely limited to mechanical breakdown due to frost action that liberates fragments of the pre-existing minerals.

white muscle disease a complex medical condition, which is multifactorial in origin but linked to selenium deficiency, causes degeneration of the muscles in animal species. In lambs born with the disease, death can result after a few days. Later in life, animals have a stiff and stilted gait, arched back, are not inclined to move about, lose condition, and die.

world Reference Base for Soil Resources a classification system, database, and atlas produced by the working group RB International Society of Soil Science in 1998.

woven bone the first deposited bone tissue that may display a haphazard distribution of matrix, cells, vascular channels, and mineral and which is usually later reworked into lamellar or haversian bone over time.

xenobiotic a chemical substance foreign to the body or introduced to the body in higher quantities or by a different pathway than occurs in normal metabolism.

X-ray diffraction maxima the periodic coherent scattering of X-rays that arises from crystalline materials. These data are used to determine the coordinates from which the space group and unit cell of the compound can be determined.

X-ray/electron diffraction the method employed to examine the crystallinity and crystal structure of materials.

zoonotic/zoonosis a disease which has a natural reservoir in an animal or non-human species that can be transmitted to humans.

Taylor Note: Please list abstracts in program in the order presented. The numbers in the poster titles are intended, please retain in the final edited version.

EARTH SCIENCE

Session Chair: Steve Taylor
Session Title: Medical Geology: A Globally Emerging Discipline at the Crossroads of Earth Science and Public Health
Location: Werner University Center

Posters

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Steve Taylor *(faculty presenter)*

Title: 1. Session Overview: Effects of Geological Environments on Human Health

Abstract: This theme session involves presentation by 19 WOU Earth Science students enrolled in ES473 Environmental Geology, spring term 2010. The focus of the session is on the emerging specialty discipline of medical geology, the study of the effect of geological phenomena on animal and human health. Since 2001, this branch of geological science has experienced a renaissance and transformation from studies that were heretofore generically referred to as "environmental health". The geological community has rightfully staked a claim to its component of the public health field with representation of the discipline in international scientific societies (e.g. International Association of Medical Geologists, Geologic Society of America Health Division), the National Academies of Science (National Research Council, 2007, "Earth Materials and Health : Research Priorities for Earth Science and Public Health"), and prominent scientific publications (e.g. Oxford University Press, 2003, "Geology and Health: Closing the Gap"; Elsevier, 2005, "Essentials of Medical Geology").

The health effects of Earth materials and geological processes are well established. Recent newsworthy examples include the disease effects spawned in the aftermath of the January 2010 Haitian earthquake, arsenic toxicity associated with groundwater supplies in the vicinity of Roseburg, Oregon, and increased cancer rates in uranium-bearing terrains of the southwestern U.S. This theme session provides an overview of the science of medical geology and case study applications from around the world. The range of topics include: introduction to medical geology as a profession, health effects of Earth materials, medical impacts of water quality, biogeochemical interactions and nutrient anomalies, anthropogenic degradation of geological environments, application of geochemistry to environmental health issues, geospatial analysis as a tool in epidemiology, health hazards associated with volcanic eruptions, global dust flux and respiratory problems, impacts of radon-arsenic-selenium-mercury-iodine on physiological function, carcinogenic associations with coal and fibrous minerals, geological effects on animal health, and geophagy (human ingestion of soil materials as a dietary supplement).

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Kelsii Dana
Faculty sponsor: Steve Taylor

Title: 2. Medical Geology: Introduction and Overview of an Emerging Discipline

Abstract: Medical Geology is an ancient and re-emerging field of science that combines elements of earth science and public health. The focus of medical geology is to decipher the impacts of geologic phenomena and other environmental factors on human health and quality of life. Significant issues in medical geology today include toxic and deficient levels of essential and nonessential minerals, exposure to radioactive elements, industrial contribution to toxic exposures, dust, and geologic events such as volcanic eruptions. The goals of medical geology are to identify sources of health hazards in the geologic environment and prevent or diminish their ill affect on humans.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Angela Devenberg
Faculty sponsor: Steve Taylor

Title: 3. Medical Geology: Example Applications and Research Directives

Abstract: Medical geology can affect humans and animals directly and indirectly. Examples include release of elemental constituents into the environment from geology sources. Arsenic, Molybdenum and Radon are a few of the compounds that pose health risks. These elements are found in drinking water and soil. Some of the health risks associated with these elements includes skin disease, reproductive problems, and lung cancer. Other phenomena include natural hazards like earthquakes and volcanoes, which may cause catastrophic deaths or long-term chronic health conditions. Geologic health hazards, from gas clouds to lahars, may cause a wide variety of health problems ranging from asthma to death. This paper will examine the spectrum of applications in the emerging field of medical geology. Geologists play an important role by recognizing what actions need to be taken to reduce and prevent the risks associated with geologic health hazards. Through educational outreach programs, geologists work to increase public awareness of environmental health issues.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Jody Berg
Faculty sponsor: Steve Taylor

Title: 4. Earth Materials at the Foundation: Geological Factors that Effect Human Health

Abstract: The Earth's crust is comprised of rock material, which in turn is composed of inorganic silicate minerals. Rock material decomposes at the Earth's surface to form regolith via chemical and physical weathering. Regolith forms the basis of soil and the fundamental framework for life in the critical zone, at the interface of the hydrosphere, atmosphere, and geosphere. Soil forms via physical, chemical and biological transformations over time. As result of pedogenic process, elements are released into surface and groundwater, and subsequently become available as part of macro- and micro-nutrients in the food chain with plants at the foundation. Essential macro-elements derived from the lithologic environment include Ca, Mg, Na, Cl, K, P, and S. Lesser abundant, but still important nutrients include Mn, Fe, Co, Cu, Zn, and Se. Deficiencies and surpluses of nutrients in the food chain effect physiological function of both animals and humans. Thus an understanding of geological variables in terrestrial ecosystems is essential for regional public health studies. This paper examines the effects of Earth materials and related near-surface processes on human health.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Mac Marshall
Faculty sponsor: Steve Taylor

Title: 5. Water Quality and Public Health

Abstract: Water is one of the most important resources on this planet, without it life wouldn't exist. The hydrosphere forms the foundation of the critical zone near the Earth's surface, in which biologic organisms flourish. The global demand for potable water is increasing while the availability and quality is decreasing. Hence, freshwater environments are of major importance to human health in both direct and indirect ways. This project examines geologic variables that influence water quality around the world, and its epidemiological effects.

A case study of groundwater quality from the Makutuapora in the Dodoma region of central Tanzania reveals a relationship between mineral-water interactions, water chemistry, bedrock geology, and microbiology. The natural geological and geochemical environment, in addition to providing beneficial elements that support plant growth, may also give rise to undesirable or toxic properties through deficiencies or anomalous excess.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Kailey Clarno
Faculty sponsor: Steve Taylor

Title: 6. Biogeochemical Cycling and Interactions: Implications for Human Health

Abstract: Before an element can be utilized by an organism, that organism must first be able to uptake it. Elements originating in geological materials are transported through soils and presented to plants in a convenient form for uptake. This project examines the pathways as nutrients are released from Earth materials and utilized by human organs.

Of the many elements on the periodic table, living organisms need about twenty of them. Eleven of these appear to be roughly constant and abundant in biological systems. Four elements (hydrogen, carbon, nitrogen, and oxygen) account for 96% of the total human body, as well as the bulk of living organisms and are termed “major elements”. The “minor elements” include sodium, magnesium, phosphorus, sulfur, chlorine, potassium, and calcium. The latter are termed electrolytes and comprise 3.78% of the human body mass. Lastly, there are eighteen essential trace elements. These nutrients are present in humans at levels that are orders of magnitude lower than found in the Earth’s crust. Metals comprise the bulk of essential trace elements available for uptake, but other important examples include selenium and iodine. Of the metals, iron is an element that is essential for many metabolic processes including oxygen transport, DNA synthesis, and electron transport. As such, this fundamental element is used as a case example to demonstrate the biogeochemical pathways starting in the soil and ending in human organs.

The impact that geology has on uptake of elements by humans and other organisms is dependent on a number biotic and abiotic variables. Understanding of the geological controls on nutrient uptake in plants and animals, including humans, is essential for deciphering public health consequences associated with deficiencies or toxicity.

11:30 a.m. – 1:30 p.m., WUC Pacific Room

Marc DesJardin

Faculty sponsor: Steve Taylor

Title: 7. Anthropogenic Factors and Human Health

Abstract: Anthropogenic releases of chemical contaminants into the geologic environment can cause significant health effects in humans and degrade ecosystems as a whole. The destruction of our natural resources for the expansion of urbanization and the pollution that urbanization creates could eventually be the fatal blow for mankind. Toxic releases have been associated with cardiovascular disease, malignant tumors, trauma and genetic anomalies. Polluting agents such as pesticides, heavy metals, petroleum compounds and industrial residues stimulate negative health feedbacks in the environment. Mankind is poisoning itself through environmental manipulation that leads to toxic releases that eventually work their way through the food chain back to mankind. This project examines the range of human-induced health risks including radiation, chemical releases, electromagnetic fields, soil contamination, agricultural degradation, and pollution.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Dan Dziekan
Faculty sponsor: Steve Taylor

Title: 8. Applied Geochemistry as a Tool in Medical Geology

Abstract: An increase of population and growth in economic development is causing adverse reactions with the surrounding environment of many areas. This population growth is responsible for changing the natural landscape and is also releasing a variety of pollutants. The combination of human-introduced chemicals, as well as those that occur geologically, have caused toxic elements to become more abundant and pose increased health risks. These pollutants can be studied using geochemical analysis of a given area, a combination of geological and chemical techniques applied in the context of public health.

The chemicals found in the Earth have been directly linked to a multitude of health problems ranging in scale from allergies to cancer fatalities. Even minimal exposures over long periods of time can have adverse effects by allowing toxic elements, such as arsenic, to build up in the body. By taking the proper steps in monitoring geochemical parameters in the environment, it is possible to mitigate exposure and reduce health risks. This paper examines a variety of techniques that are used to determine the level of potentially dangerous chemicals occurring in the hydrosphere and geosphere. This work is placed in the context of case studies associated with agricultural and forestry practices.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
William Vreeland
Faculty sponsor: Steve Taylor

Title: 9. Geographic Information Systems and Geospatial Analysis: A 21st Century Tool for Epidemiology and Public Health Management

Abstract: Epidemiological studies involve analyzing public health factors in the context of time and space, with the goal of mitigating disease outbreaks. Emerging advances in computer processing power and cost are facilitating research into linkages between geospatially-distributed risk factors for illness and disease. Geographic Information Systems (GIS) provide a software technology that allows scientists to easily link public health databases to geospatial information and forms the cornerstone of epidemiology in the 21st century.

Improved resolution of datasets allows visual representation of complex, multilayered, logical, numerical, and statistical relationships between populations, risk factors, and known or hypothesized causal factors. Geospatial relationships combined with raw and processed data enable researchers to identify, mitigate, or prevent both epidemic and endemic disease fostered by vectors that have a geographic component. This developing technology comes with the cost of upgrading computer workstations and network bandwidth to accommodate the geometrically increasing size of the datasets, however the potential benefits to public health management are significant. This paper provides an overview of GIS applications in the public health sector, and presents case studies demonstrating the efficacy of the technology.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Alyssa Marquez
Faculty sponsor: Steve Taylor

Title: 10. Regional Medical Geology: Global Health Trends and Geographic Case Studies

Abstract: The field of medical geology studies the effects of geological materials on the health of both humans and animals. Plate tectonics, crustal lithology, and climate of any given region are spatially variable and have a direct influence on the input of elements into the soil, air, and water. Health issues associated with regional geologic variation have been observed all over the world. Tectonic and surface hazards (e.g. earthquakes, volcanic eruptions, floods, landslides, tsunamis) catastrophically impact social infrastructure, and in turn spawn a host of public health issues. Other examples include degraded water quality and anomalous concentrations of essential elements that also lead to adverse health effects. This paper provides a sampling of regional case studies in medical geology and demonstrates the geographic variability of health conditions associated therein.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Kevin Friscia
Faculty sponsor: Steve Taylor

Title: 11. Health Effects from Volcanic Eruptions

Abstract: Volcanic processes operated on Earth long before the onset of planetary life and biological evolution. Humans have long lived in the shadows of active volcanoes, with catastrophic deaths in proximal eruptive zones the most obvious hazard. Only in the past several decades have geoscientists begun monitoring the long term effects that volcanic emissions have on human health. Living near vents causes hazards associated with pyroclastic and lava flows, while farther away, fine atmospheric tephra pose other health problems. This study focuses on the long-term health effects from volcanic eruptions. Ejecta containing hot ash, gases and dust commonly result in inhalation, short-term respiratory stress, skin and ocular irritation. Inhalation of volcanic gases (e.g. SO_2, H_2S, SO_3, H_2SO_4) can lead to chronic respiratory disease and death. Understanding of the long- and short-term effects associated with volcanic eruptions is essential for developing public heath strategies and hazards mitigation plans in tectonically active regions. Both regional and global case studies are presented to demonstrate the relevance of medical geology with respect to applied practice.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Carlie Bulen
Faculty sponsor: Steve Taylor

Title: 12. The Effects of Global Dust Flux on Human Health

Abstract: One field of study in medical geology examines the effects of atmospheric dust on human health. These effects can have significant health consequences, but are not widely recognized in the literature. Dust inhalation and lung accumulation is known to cause long term chronic health conditions. Sources in the atmosphere include wind deflation, burning of vegetation, volcanic eruptions, and anthropogenic disturbance. Classic locations associated with dust-related lung complications include the great dry lands of the northern hemisphere, the U.S. Great Basin, and southern hemisphere arid regions of Australia, South America and southern Africa. These locations are notoriously associated with high rates of silicosis and asbestosis, and attendant lung disease. Factors that influence the severity of these conditions include duration of exposure, the size of particles inhaled, and the toxicity of minerals comprising the particles. One detrimental element found in dust particles that is linked to a significant number of these conditions is silica. Although dust-related lung disease is a significant problem in underdeveloped countries and desert regions, few public health actions are being implemented to mitigate harmful effects of dust inhalation. This paper presents an overview of the geological influences on global dust flux and case examples of chronic health effects associated with excessive inhalation.

11:30 a.m. – 1:30 p.m., WUC Pacific Room

Joni Osborn

Faculty sponsor: Steve Taylor

Title: 13. Radon: A Deadly Carcinogen in the Geologic Environment

Abstract: Radon is a naturally occurring noble gas that results from radioactive decay in uranium-bearing bedrock and regolith. Radon occurs in a variety of geologic settings around the world, including the United States. Bedrock sources most associated with radon include metamorphic rocks and granites, black shales, feldspathic glacial deposits, and uranium ores. Health hazards associated with this gas include lung and stomach cancers, caused primarily by inhalation or ingestion. Radon exposure increases chances of lung cancer deaths in smokers and miners who work in underground enclosures.

Radon hazard mapping helps locate risk areas and guides public health protection. Global hot spots for radon exposure include the Sierra Nevada-Rocky-Appalachian mountain regions of the U.S., glacial terrains of the upper Midwest, Great Britain, Norway, and the Czech Republic. This paper provides an overview of the geochemistry behind radon occurrence and presents examples of mitigation projects from around the world.

11:30 a.m. – 1:30 p.m., WUC Pacific Room

Riccilee Keller

Faculty sponsor: Steve Taylor

Title: 14. The Problem with Geogenic Arsenic and Global Health Effects

Abstract: The 20th most abundant element found in the Earth is Arsenic (As). This element naturally occurs as As (III) and As (V). These two oxidation states determine toxicity levels and control its fate and transport into the human body, via geologic processes. Sources of arsenic exposure include contaminated ground water, coal, geothermal springs, volcanic sediments, and anthropogenically-related releases. Arsenite (H_3AsO_3) is the dominant species of As (III) in solution and is strongly absorbed onto iron oxides and other soil constituents (e.g. clay). Arsenate (H_3AsO_4) is the most common form of As (V) and highest absorption rates occur when pH falls between 4 and 7. As is highly mobile in the hydrosphere and poses a widespread public health concern.

Exposure to Arsenic can come from both natural and anthropogenic activities. The most common toxic pathway is via groundwater, where the most acute cases are associated with Asian countries. West Bengal and Bangladesh, in particular, suffer from rampant arsenic poisoning, often interpreted as the result of agricultural irrigation. In heaviest impacted areas, concentration levels range up to 500 ppb (parts per billion), whereas background levels usually average between 3 and 20 ppb. China's Guizhou Province suffers from As poisoning via lithologic pathways, thought to be intensified by use of domestic coal fuel associated with concentrations up to 3500 ppb. Long term exposure to As, whether air born, in food supplies, or drinking water, may result in cardiovascular disease, neurological disorders, skin depigmentation, rhagades, hyperkeratosis and Bowen's Disease (squamous cell carcinoma). This paper examines the global impact of environmental arsenic and its range of human health effects.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Von Blanchard
Faculty sponsor: Steve Taylor

Title: 15. Arsenic Occurrence and Health Risks in Aquifer Systems of Western Oregon

Abstract: Arsenic concentrations in groundwater of western Oregon commonly exceeds the maximum concentration limits (MCL) specified by the U.S. Environmental Protection Agency. Arsenic varies spatially according to composition of bedrock aquifer materials and temporally with seasonal changes in climate-driven recharge. Select aquifer systems in Lane and Linn Counties, the Tualatin basin, and the Sutherlin area are associated with anomalous arsenic concentrations in groundwater. Arsenic toxicity and long term health effects pose a risk to rural water users and well owners in these areas. This paper examines the geochemical conditions associated with arsenic distribution in western Oregon and considers mitigation strategies with respect to public health practice.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Caitlin Morris
Faculty sponsor: Steve Taylor

Title: 16. Geochemical Controls on Selenium Occurrence in the Environment: Dietary Balancing Between Deficiency and Toxicity

Abstract: Recent advances in medical geology have improved scientific understanding of the role of selenium (Se) as an essential trace element in human health. Even though selenium is an essential element, it has one of the narrowest concentration ranges between physiological deficiency and toxicity, either of which is potentially detrimental to bodily function. Se deficiency is directly correlated with Keshan Disease (KD), a heart ailment mainly affecting women and children, and Kashin-Beck Disease (KBD), which leads to deformity of the feet and hands. The effects of Se toxicity are less dramatic than those associated with deficiency, but just as efficient in causing health-related discomfort. This project examines the role of selenium geochemistry in human health, and provides case examples of public health issues from around the world.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Trista Ten Clay
Faculty sponsor: Steve Taylor

Title: 17. Geologic Occurrence of Mercury and Iodine: Health Concerns in the 21st Century

Abstract: The emerging field of medical geology provides a unique perspective to the many health effects caused by iodine and mercury in the natural environment. Iodine in small quantities is an important element that helps the body retain and use water, making it vital to human and animal health. Overexposure and underexposure of iodine may cause very serious and sometimes deadly effects. In contrast, mercury is a toxic metal that is tolerable to physiological function in small amounts; but the process of bioaccumulation and incremental increases in the food chain creates a threat of overexposure. Case studies are examined to understand the geologic controls on the mercury and iodine occurrence. Examples include a goitre occurrence in Sri Lanka, excessive iodine accumulation in southeast Asia, mercury toxicity in the gold fields of Kenya, and bioaccumulation potential in regional food supplies.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Kacey McCallister
Faculty sponsor: Steve Taylor

Title: 18. Impacts of Mineral Resource Extraction: The Effects of Coal and Asbestos Residues on Human Health

Abstract: Coal and fibrous minerals have many adverse health effects in those individuals that encounter them through mining, industrial processing, or domestic use. Certain coals that are found in China are used to dry crops such as corn and peppers, and in cooking. Unfortunately the coal that is available in that region contains high amounts of arsenic and fluoride. Exposure leads to many health issues such as decay of the teeth, bowed and crippled limbs, and scaly skin. Another mineral resource with direct and harmful side effects is asbestos. Asbestos minerals tend towards a fibrous habit that is very dangerous to the body because of their ability to enter into the lungs and alter cell function. Those afflicted with respiratory illnesses slowly find it harder to breath because of tissue hardening over time. This paper examines the effects of mineral resource extraction and the effects residual environmental release on human health.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Rachel Johnson
Faculty sponsor: Steve Taylor

Title: 19. Bedrock Composition, Soil Chemistry and Animal Health: Global Case Studies in Applied Medical Geology

Abstract: This paper examines relationships between regional bedrock geology, soil composition, and plant nutrient quality. Animals are affected by changes in bedrock composition and attendant soil mineralogy. Mineral deficiencies and poisonings occur due to geochemical anomalies in a given region. Mineral imbalances can also cause diseases as the excessive uptake of one element blocks absorption of other necessary nutrients. Changes in soil moisture, organic matter content, clay content, pH levels, cation exchange capacity affect bulk soil chemistry and hence plant nutrient uptake. Plants in turn absorb these elements and sicken foraging animals if they do not contain the proper mineral balance. Deficiencies are further exacerbated by droughts, excessive snowfall, and temperature extremes that restrict animal diets to less efficient food sources.

Case studies are presented to illustrate bedrock-plant nutrient associations. Farmers have experienced ruminants succumbing to molybdenosis and copper deficiency. Molybdenum creates an endocrine imbalance leading to weight loss, lethargy, emaciation, and behavioral disturbances. Wild herbivores are most affected by excessive or deficient mineral quantities in plants. For example, Swedish moose commonly develop type-2 diabetes due to chronic molybdenosis and elevated glucose levels. In Africa, animal migration patterns follow the availability of plants that contain essential trace elements that are endemic to a particular geologic terrain.

11:30 a.m. – 1:30 p.m., WUC Pacific Room
Lindsey Robinson
Faculty sponsor: Steve Taylor

Title: 20. Geophagy: The Effects of Soil Ingestion on Human Diet and Health

Abstract: Geophagy is the ingestion of soil, either involuntarily or deliberately. Foods can be contaminated, dust may be inhaled, or it can be a part of a person's everyday diet. Deliberate geophagy has been in existence since before the evolution of *Homo sapiens*, however it was first recorded in the 1st century A.D. when *terra sigillata* was used for medicinal purposes. This composite substance was made from a soil that comes from the Greek island of Lemnos, mixed with goat's blood and dried into a nickel-sized tablet. These tablets were used for many medicinal purposes and was listed in medical journals up through 1848. In the "New World" many natives practiced geophagy, though most only used it in times of great famine or for suicide. Geophagy in the U.S. today, though not widely admitted for obvious reasons, can be attributed to the practices of the slaves brought over from Africa in the early years of our nation's history.

Some reasons for modern day geophagy include: food or a food detoxifier, treatment of psychological disorders, use as a pharmaceutical, cultural tradition, or as a form of suicide. Claimed benefits of geophagy include relief of pregnancy symptoms or use as a mineral supplement. Side effects include elemental deficiencies, toxicities, and anxillary ingestion of soil-borne pathogens. This paper examines the history and practice of geophagy in medical applications.

Med Geo Field Guide

DESCHUTES RIVER BASIN
FIELD NOTES

O'Connor And Grant, 2003
Deschutes Geomorphology

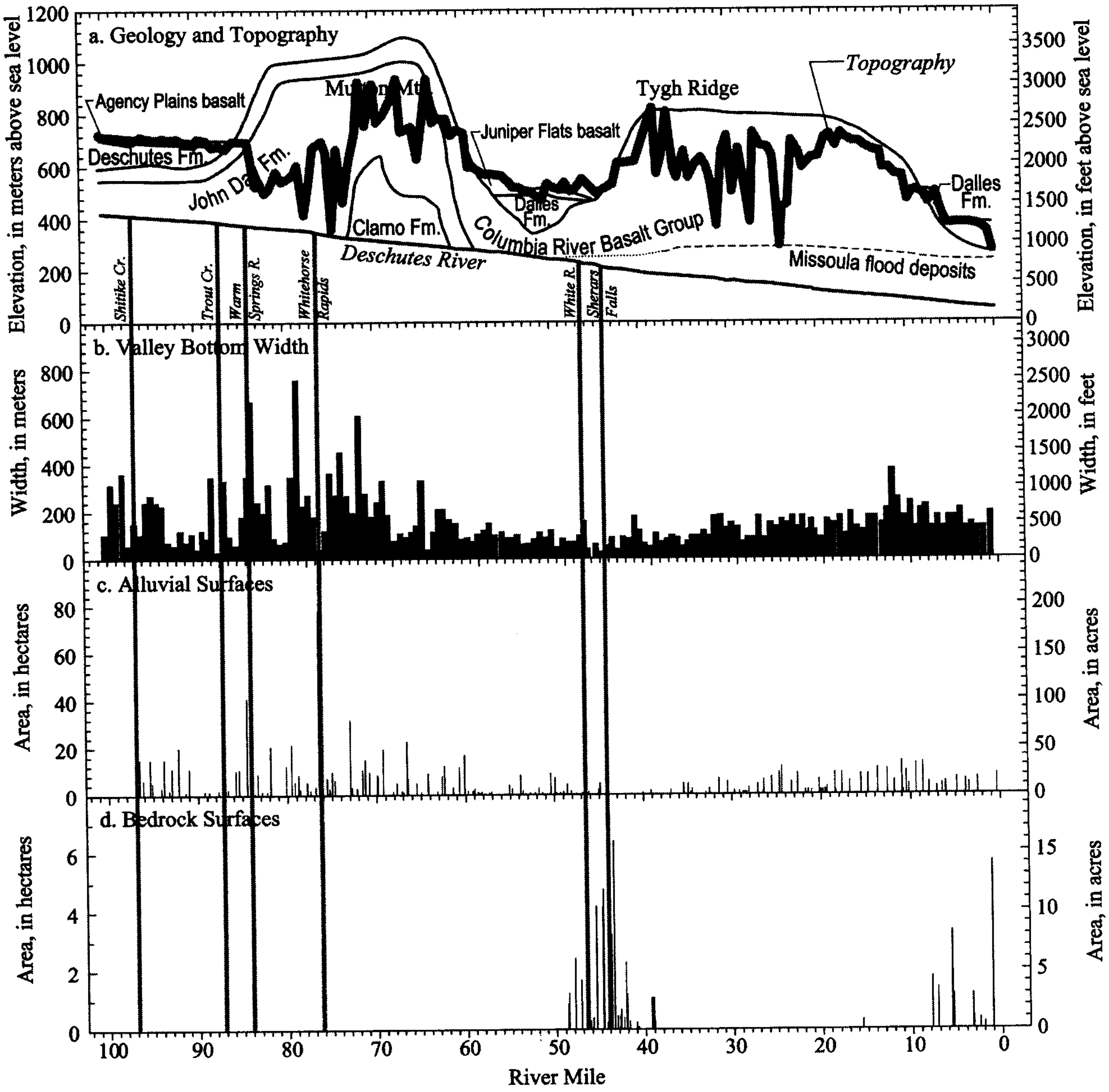

Figure 3. Canyon and valley-bottom characteristics of the lower Deschutes River. (a) Deschutes River profile and generalized geology and topography. River profile from elevation data on USGS 7.5-minute topographic maps. Topography is represented by the highest point within 2 km of the Deschutes River channel, measured from transects placed orthogonal to the channel and spaced at 1 km increments on USGS 7.5-minute topographic maps. Pre-Quaternary geology of the valley walls along the river generalized from position of contacts on 1-km spaced transects oriented perpendicular to the channel. Contact positions, in downstream order, after *Smith* [1987], *Smith and Hayman* [1987], *Waters* [1968a, b], *Bela* [1982], *Sherrod and Scott* [1995], and *Newcomb* [1969]. The distribution of Missoula flood deposits blanketing older rocks was mapped from aerial photographs and field reconnaissance. (b) Width of the valley bottom, as measured from transects oriented perpendicular to the channel and spaced at 1-km increments. (c) Distribution and size of alluvial surfaces within the valley bottom. (d) Distribution and size of bedrock surfaces within the valley bottom.

O'CONNOR AND GRANT, 2003
DESCHUTES GEOLOGY

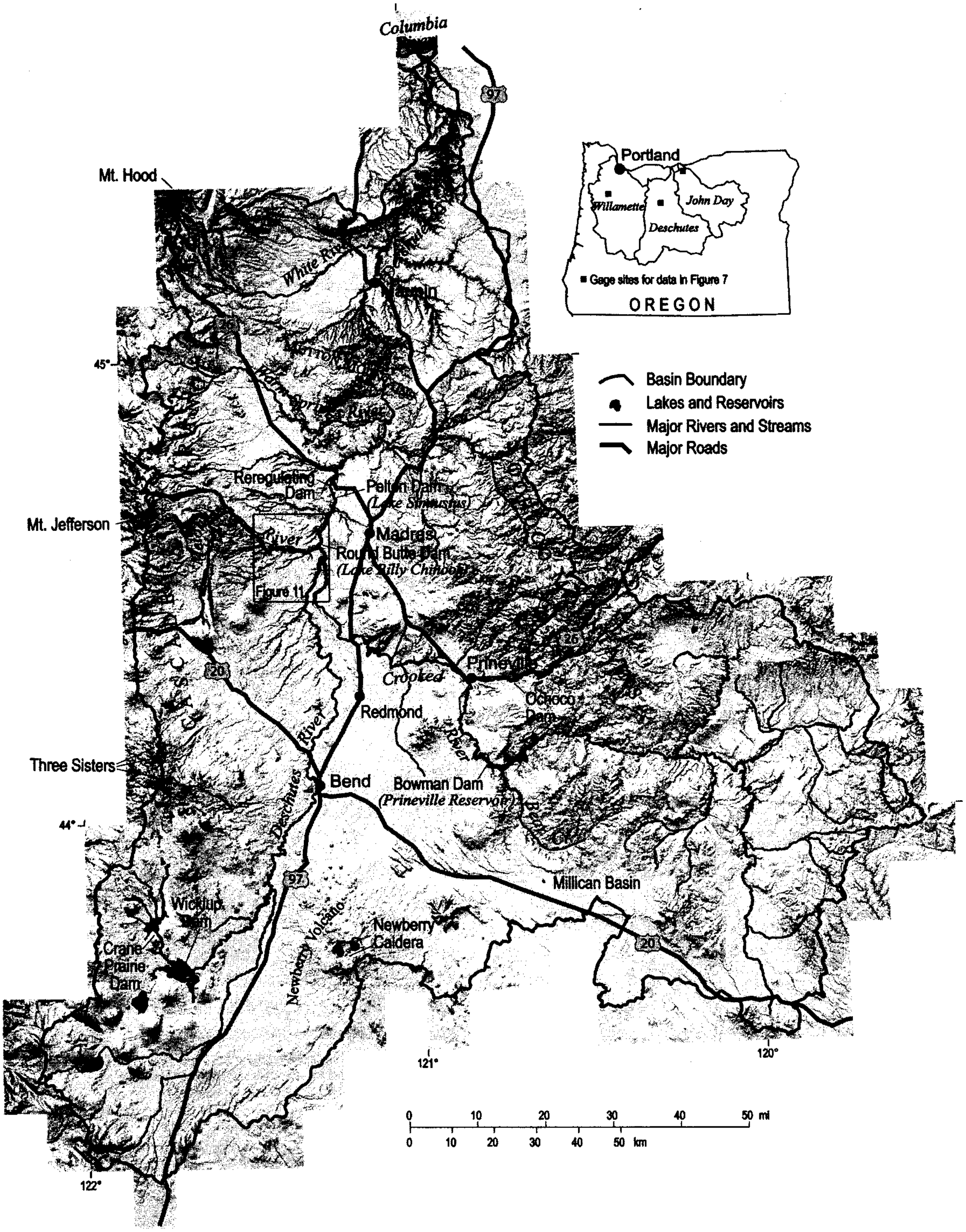

Figure 1. Location map showing major physiographic and cultural features of the Deschutes River basin. Hillshade topographic base derived from U.S. Geological Survey 30-m resolution digital elevation data.

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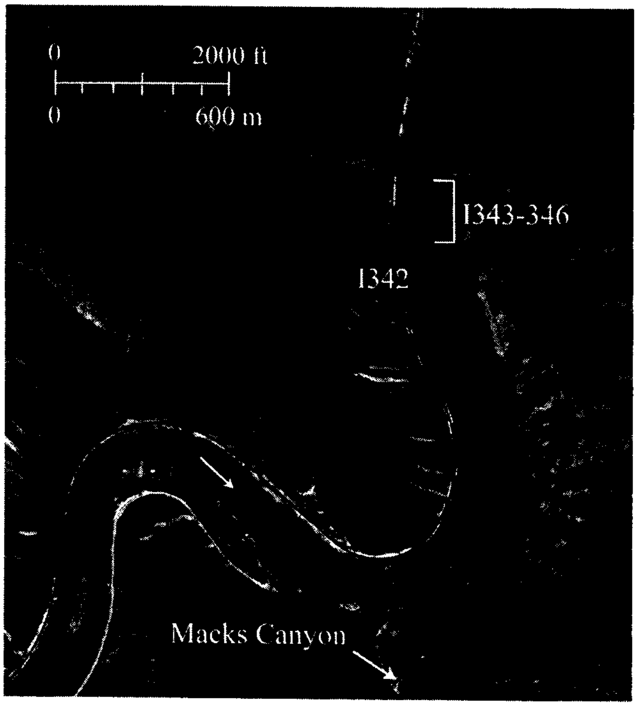


Figure 10. Airstrip Island (Island 342) is cored by gravel, cobbles, and boulders up to 0.5 m in diameter and was not overtopped in the February 1996 flood, evidence that it was formed by outsized flooding. Islands 343 through 346 are inferred to have been deposited at the same time, such that the entire group of five islands is an erosively modified transverse bar. Aerial photograph dated 1995, Portland General Electric.

Large Quaternary mass movements directly or indirectly account for the six named rapids between RM 100 and 50 [*O'Connor et al.*, this volume]. Trout Creek Rapids is composed of 2- to 3-m-diameter boulders deposited during a flood that apparently resulted from a landslide-dam breach. Whitehorse Rapids is the remnant of a landslide dam formed by a large, late Pleistocene mass movement at RM 76 (Figure 11c). Similarly, mass movement from the left valley slope near Dant temporarily dammed the Deschutes River at RM 64 and left a lag of large boulders that now form Buckskin Mary Rapids (Figure 11a). Four Chutes Rapids, 1 km downstream, is composed of remnants of coarse debris brought to the valley bottom and redistributed by floodwaters escaping the breached dam at Buckskin Mary Rapids. Wapinitia and Boxcar Rapids (Figure 11d) formed where large landslides moved onto the valley bottom and have either blocked or partially diverted the channel.

White River Rapids, Bull Run Rapids, Harris Rapids (Figure 9d), and Colorado Rapids are all reaches where the Deschutes River flows over and through accumulations of large boulders. In each instance, these boulder fields are near termini of Outhouse Flood bars, leading us to infer that the rapids developed in lags of coarse deposits of the Outhouse Flood (Table 4).

Table 4. Name, location, rating, and formative process for major Deschutes River rapids

Rapid	Location (RM)[1]	Class[2]	Formative Process
Upper Trout Creek	87.0	3	outsized flood
Lower Trout Creek	86.9	3	outsized flood
Whitehorse	76.1	4	mass movement
Buckskin Mary	63.8	3	mass movement
Four Chutes	63.4	3	mass movement
Wapinitia	54.7	3	bedrock
Boxcar	53.7	3	mass movement
Oak Springs	47.3	4	bedrock
White River	46.3	3	outsized flood
Upper Rollercoaster	45.7	3	bedrock
Lower Rollercoaster	45.4	3	bedrock
Osborne	45.0	3	bedrock
Sherars Falls	44.0	6	bedrock
Bridge	43.6	3	bedrock
Wreck	40.0	3	bedrock
Bull Run	18.4	3	outsized flood
Jet Pump	15.5	3	bedrock
Harris	11.4	3	outsized flood
Washout	7.8	4	tributary
Gordon Ridge	5.9	3	bedrock
Colorado	4.2	4	outsized flood
Rattlesnake	2.7	4	bedrock
Moody	0.8	3	bedrock

[1] River mile

[2] Rating obtained from BLM brochure "Welcome to the Lower Deschutes River," undated. Scale varies from Class 1, beginner, to Class 6, unrunnable. Only rapids Class 3 or greater are included.

Coarse debris delivered by tributaries has formed just one major rapid on the lower Deschutes River. Washout Rapids contains information on over 40 native fish species occurring in Oregon. The salmonids are the most widespread group of fish in the state and best-recognized as an indicator of watershed health. These are a class of fish that include salmon, trout, and ***char***. This assessment process focuses on evaluating salmonid populations and habitat conditions. In areas where there are sensitive nonsalmonid fish species, this approach may be adapted to evaluate the specific needs of those species.

Salmonids have a wide variety of life history patterns (Figure 16). They may be ***anadromous***—spending some portion of their life history in the ocean and returning to freshwater streams to spawn. They may be ***resident*** and spend their entire lives in the stream network. Or they may move between large river systems or reservoirs and the stream network where they were born.

Chinook, coho, steelhead, and cutthroat trout are the most common anadromous salmonids occurring in Oregon. Anadromous chum salmon and kokanee/sockeye salmon also occur in Oregon, but have more limited distributions. Redband (rainbow) trout and interior cutthroat trout are the most common resident salmonids; bull trout also occur in Oregon but have a limited distribution. The life history patterns and distribution in the stream network of the most common salmonids are summarized in Table 1 and described in the following paragraphs (Figure 17). These descriptions are general in nature; it is not uncommon for fish species to have life history patterns adapted to the watershed of origin. For this reason the Fish and Fish Habitat Assessment component asks users to describe the known life history patterns of fish occurring in their watershed. The *Biennial Report on the Status of Wild Fish in Oregon* provides some watershed-specific information and contains more detailed information on the life history patterns of nonsalmonid fish species that may occur in your watershed.

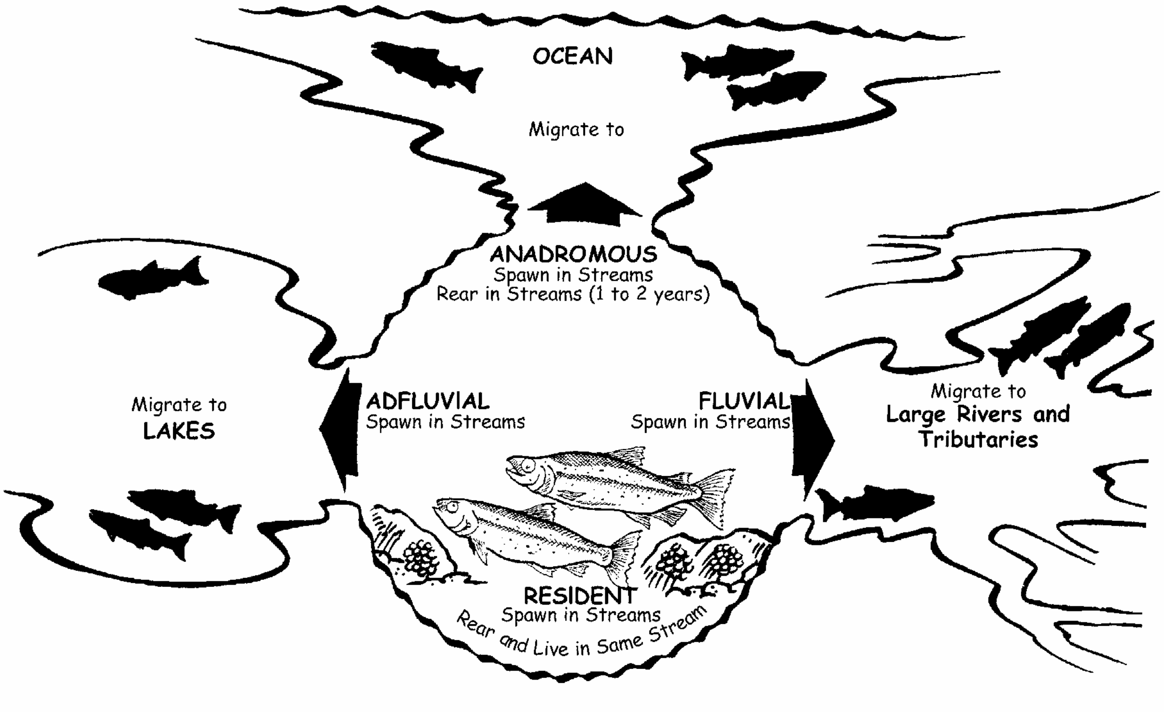


Figure 16. Salmon and trout have three distinct life history patterns: (1) "anadromous," spending some portion of their life history in the ocean and returning to freshwater streams to spawn; (2) "resident," spending their entire lives in the stream network; or (3) fluvial or adfluvial, moving between large river systems or reservoirs and the stream network where they were born.

O'CONNOR AND GRANT, 2003
DESCHUTES FISH POPULATION

Table 1. Fish species present in the Deschutes River Basin.

Common Name	Scientific Name	Origin
Pacific lamprey	*Entosphenus tridentatus*	Native
Steehead/Rainbow trout	*Oncorhynchus mykiss*	Native
Chinook salmon	*Oncorhynchus tshawytscha*	Native
Sockeye salmon/ Kokanee	*Oncorhynchus nerka*	Native
Bull trout	*Salvelinus confluentus*	Native
Mountain whitefish	*Prosopium williamsoni*	Native
Shorthead sculpin	*Cottus confusus*	Native
Torrent sculpin	*Cottus rhotheus*	Native
Slimy sculpin	*Cottus cognatus*	Native
Mottled sculpin	*Cottus bairdi*	Native
Prickly sculpin	*Cottus asper*	Native
Longnose dace	*Rhinichthys cataractae*	Native
Speckled dace	*Rhinichthys osculus*	Native
Chiselmouth	*Acrocheilus alutaceus*	Native
Largescale sucker	*Catostomus macrocheilus*	Native
Bridgelip sucker	*Catostomus columbianus*	Native
Northern pikeminnow	*Ptychocheilus oregonensis*	Native
Redside shiner	*Richardsonius balteatus*	Native
Threespine stickleback	*Gasterosteus aculeatus*	Unknown
Brook trout	*Salvelinus fontinalis*	Introduced
Brown trout	*Salmo trutta*	Introduced
Atlantic salmon	*Salmo salar*	Introduced
Largemouth bass	*Micropterus salmoides*	Introduced
Smallmouth bass	*Micropterus dolomieu*	Introduced
Yellow perch	*Perca flavescens*	Introduced
Brown bullhead	*Ameiurus nebulosis*	Introduced

salmon have been defined in the Deschutes River basin on the basis of timing of adult migration from the ocean, age at out-migration of juveniles, and location of spawning [*Jonasson and Lindsay*, 1988; *Lindsay et al.*, 1989]. Fall chinook salmon (also known as "ocean-type" chinook salmon) typically spawn in mainstem reaches and the resulting progeny migrate to the ocean within a few months after emergence from the gravel [*Jonasson and Lindsay*, 1988; *Healey*, 1991]. Spring chinook salmon (or "stream-type" chinook salmon) spawn in headwater tributaries, and the juveniles remain in these streams for over a year before migrating to the ocean [*Lindsay et al.*, 1989; *Healey*, 1991]. Returning to their natal streams after about two or three years in the ocean, adult spring chinook salmon enter freshwater during the late spring and hold in cold pool habitats until the fall when they spawn. Fall chinook return to freshwater during the late summer or fall and spawn in October or November.

Spring chinook salmon historically spawned in the west side tributaries to the Deschutes River including the Warm Springs River, Shitike Creek, and the Metolius River (Figure 3). In the Deschutes River, Big Falls at River Mile (RM)[1] 132.2 was the upstream extent of spring chinook salmon [*Nehlsen*, 1995] (Figure 4). Anecdotal reports suggest that spring chinook salmon might have spawned in the Crooked River [*Nehlsen*, 1995]. At maturity, spring chinook are typically 60 to 90 cm long and attain weights of approximately 7 kg.

Fall chinook salmon are the largest salmonids in the Deschutes River basin, attaining lengths of 70 to 110 cm and

---

[1] Units given are metric except for locations, which are given as river miles (RM), or miles upstream from the river mouth as marked on USGS topographic maps. These values are close to, but not necessarily the same as, actual distances along the present channel. Fractional river miles given herein are based on interpolations between these published river miles.

Deschutes River Geology, Geomorphology and Hydrology
Summary Notes

O'Connor, J.E., and Grant, G.E., eds., 2003, A peculiar river: geology, geomorphology, and hydrology of the Deschutes River, Oregon: American Geophysical Union, Water Science and Application 7, 219 p.

Foreward (Wolman):

Deschutes River

- -80% of mean annual Q is from groundwater sources
- -For two largest historic floods: 70% of Qpeak came from 26% of drainage area
- -Peak flood flows < five times mean annual flow
- -Low annual sediment load: 4-6 ton/sq. km/yr
- -Precipitation Range: 2000 mm on west, near Cascades to <200 on eastern portion

Introduction (O'Connor and Grant):

-Groundwater control of discharge renders mean annual flow very stable on Deschutes

-Unique Aspects of Deschutes

- drains east of uplifted Cascade volcanic arc
- basin lies in tectonically-derived rainshadow
- deep groundwater systems supports stable discharge regime
  - cool river temperatures / good fish habitat in otherwise arid landscape
  - stable flows and stable annual hydrographs
  - surface flows buffered by groundwater system
- limited surface runoff / arid conditions
  - low drainage densities
  - low angle slopes
  - low historic / late Holocene sediment production and delivery to channels

Geology, Geomorphology, Hydrology (O'Connor, Grant, and Haluska)

Deschutes Background

-Drainage area = 26860 sq. km
-Drains north for 300 km into Columbia
-Pelton-Round Butte Dam located 160-180 km upstream from mouth

Geologic Setting

-majority of basin underlain by Cenozoic (<65 m.y.) volcanic rocks
- rock ages generally young from east to west across basin

east edge: Mz / Pz metamorphic and sed rks

North-central basin: Eocene-Oligocene John Day and Clarno Fms
(volcanic, volcaniclastic, and sed. rocks)

Northern margin: overlain by Miocene Columbia River Basalts

- eastern Deschutes = Picture Gorge basalts, from John Day area
- northern Deschutes = younger CRBs from eastern WA/OR

Post-CRB (Miocene-Pliocene)

- deformation of CRB
- volcanic eruptions/lahars of Simtustus, Deschutes, and Dalles Formations (15-4 m.y.)
  - plus Rattlesnake Ashflow Tuff in SE part of Deschutes basin
- Rim-capping, Pliocene basalt flows are intermixed with river gravels 275 m above present river level
- Western edge of Deschutes basin marked by < 2 m.y. high cascade volcanic arc rocks

River incision rates: river level / gravels at 275 m elevation = 4 m.y. old, deposits along present river drainge < 1 m.y. old: incision rate from 4 m.y. to 1 m.y. = 0.1 mm/yr = 0.1 m / 1000 yr = 100 m / m.y.

Topography

- Eastern Highlands Terrane (Ochoco Mtns. / Crooked River sub-basin)
  - John Day / Clarno Formations (55-20 m.y. – claystone, siltst, ashflow tuff)
    - Susceptible to landsliding, most landslides spawned from these formations
- Young Volcanic Terrane – southern and southwestern part of basin
  - High Cascades to west / SW
  - Newberry Volcano on east /SE
  - Localized glacial outwash
  - 7000 yr old Mazama ash
  - faulting / channel-damming lava flows
  - low-relief alluvial and lacustrine landscape
- Northern Canyon Terrane
  - Basalt-canyons, rim rock country
  - Cliff-forming CRB's underlain by John Day / Clarno Formations
  - Landslide-dominated uplands of the John Day / Clarno Formations
  - steep canyon slopes and drainage densities

Hydrology

- drainage area = 26860 sq. km
- average annual runoff = 5.2×10^9 m^3 = 0.19 m of runoff over entire basin
- highest precip. on western basin with input from eastern high Cascades
- arid / rainshadow conditions on eastern side of basin
- Gage at mouth of Deschutes / Columbia
  - Avg. Feb. flow = 213 cms
  - Avg. Aug. flow = 124 cms low overall variation, given seasonal snowmelt
  - Wet season / dry season discharge = 1.5 times

For comparison: John Day River: Wet season/dry season discharge = 30 times; Willamette = 10 times

- Largest historic peak flow =540 cms in Feb. 1962 (< 5 times mean flow)

(comparison John Day/Willamette peak flow record = >20 times mean annual flow)

- Interpretation of Steady Annual Flow Conditions
  - Poorly integrated surface drainage in eastern basin
  - Seasonal snowmelt in western basin infiltrates into young volcanic rocks, forms extensive groundwater discharge buffering system
  - Eastern sub-basins show strong seasonal fluctuation/snow melt but have small drainage areas

Sediment Production

- Little work done basin-wide on sediment budgets
- Most historic sediment data collected at Pelton-Round Butte Dam
- Highest long-term sediment yields generally associated with glacial climates / outwash on western boundary (Cascades) of basin and also volcanic eruptions / volcaniclastics (e.g. Mazama ash to south)
- Historic sediment yields from reservoir studies:
  - 4- 6 tons / sq km / yr (i.e. low sediment yields compared to other rivers)

Summary of Important Characteristics

- moral of story: steady discharges and low sediment yields are evident from modern studies
- present topography / geomorphology of Deschutes:
  - present north-flowing course established ~12 m.y. ago
  - Canyon incision occurred between 4 and 1 m.y. ago/ with localized aggradation / incision events
- Southern, upstream portion of basin underlain by permeable young volc. Rocks – results in strong groundwater control on discharge
- Young volcanic rocks to south and east produce little sediment; primarily assoc. with glacial outwash
- Eastern Highlands underlain by John Day / Clarno Formations, results in more extensive landsliding and greater sediment influx
- Steady stream flows and low sediment delivery result in low sed. Yields overall
- Over time scales of thousands to millions of years: most sediment production is associated with (1) volcanic eruptions, lahars, landslides (in John Day/Clarno), glacial climatic episodes, or incision events

Med Geo Field Guide

APPENDIX

Periodic Table of the Elements

1 IA 11A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown

Lanthanide Series	57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide Series	89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Understanding Units of Measurement

Technical environmental reports involving soil, water, or air contamination often report numerical values in units unfamiliar to people who don't routinely read these types of reports. The different units of measurement can be confusing. This brief is intended to help people understand measurement units they may see in technical environmental reports. Examples of typical units of measurement are given below.

Numbers

Million = 1,000,000

Billion = 1,000,000,000

Trillion = 1,000,000,000,000

One millionth = 0.000001

One billionth = 0.000000001

One trillionth = 0.000000000001

Volume

One liter (L) = 1.06 quarts

One cubic meter (m^3) = 35.31 cubic feet (ft^3)

One cubic meter (m^3) = 1,000 liters (L)

One liter (L) = 1,000 milliliter (ml) = 1,000 cubic centimeters

Mass

28 grams = about 1 ounce

1 kilogram (kg) = 1,000 grams

1 milligram (mg) = 1/1,000 gram = 0.001 gram

1 microgram (ug) = 1/1,000,000 gram = 0.000001 gram

1 nanogram (ng) = 1/1,000,000,000 gram = 0.000000001 gram

1 picogram (pg) = 1/1,000,000,000,000 gram = 0.000000000001 gram

Concentrations in Soil

Concentrations of chemicals in soil are typically measured in units of the mass of chemical (milligrams, mg or micrograms, ug) per mass of soil (kilogram, kg). This is written as mg/kg or ug/kg. Sometimes concentrations in soil are reported as parts per million (ppm) or parts per billion (ppb). Parts per million and parts per billion may be converted from one to the other using this relationship: 1 part per million = 1,000 parts per billion.

For soil, 1 ppm = 1 mg/kg of contaminant in soil, and 1 ppb = 1 ug/kg. A measurement of 6 mg/kg is the same as 6 ppm or 6,000 ppb, which is equal to 6,000 ug/kg.

Concentrations in Water

Concentrations of chemicals in water are typically measured in units of the mass of chemical (milligrams, mg or micrograms, ug) per volume of water (liter, L, l).

Concentrations in water can also be expressed as parts per million (ppm) or parts per billion (ppb). Parts per million and parts per billion may be converted from one to the other using this relationship: 1 part per million = 1,000 parts per billion.

For water, 1 ppm = approximately 1 mg/L (also written as mg/l) of contaminant in water, and 1 ppb = 1 ug/L (also written as ug/l). A measurement of 6 mg/L is the same as 6 ppm or 6,000 ppb, which is equal to 6,000 ug/L.

A way to visualize one part per billion (ppb) in water is to think of it as one drop in one billion drops of water or about one drop of water in a swimming pool. One part per million is about 1 cup of water in a swimming pool.

Occasionally, concentrations of chemicals in water may be written as grams per cubic meter (g/m^3). This is the same as grams per 1,000 liters, which may be converted to milligrams per liter (mg/L). Therefore, 1 g/m^3 = 1 mg/L = 1 ppm. Likewise, one milligram per cubic meter (mg/m^3) is the same concentration in water as one microgram per liter (ug/L), which is about 1 ppb.

Concentrations in Air

Concentrations of chemicals in air are typically measured in units of the mass of chemical (milligrams, micrograms, nanograms, or picograms) per volume of air (cubic meter or cubic feet). However, concentrations may also be expressed as parts per million (ppm) or parts per billion (ppb) by using a conversion factor. The conversion factor is based on the molecular weight of the chemical and is different for each chemical. Also, atmospheric temperature and pressure affect the calculation.

Typically, conversions for chemicals in air are made assuming a pressure of 1 atmosphere and a temperature of 25 degrees Celsius. For these conditions, the equation to convert from concentration in parts per million to concentration in milligrams per cubic meter (mg/m^3) is as follows:

Concentration (mg/m^3) = 0.0409 x concentration (ppm) x molecular weight

To convert from mg/m^3 to ppm, the equation is as follows:

Concentration (ppm) = 24.45 x concentration (mg/m^3) ÷ molecular weight

The same equations may be used to convert micrograms per cubic meter (ug/m^3) to parts per billion (ppb) and vice versa:

Concentration (ug/m^3) = 0.0409 x concentration (ppb) x molecular weight

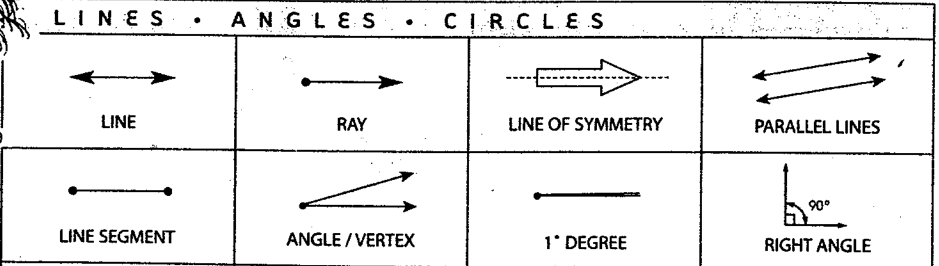
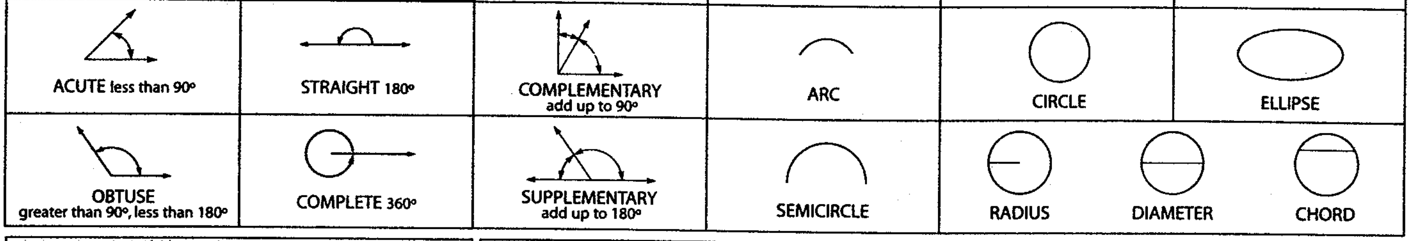
Or, concentration (ppb) = 24.45 x concentration (ug/m^3) ÷ molecular weight

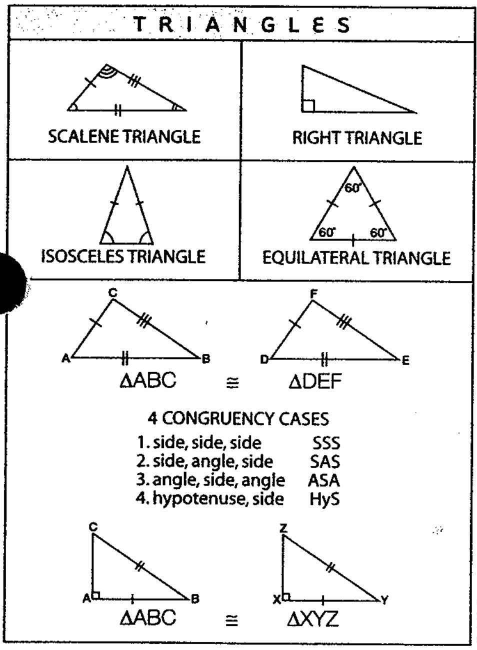
Here is an example. The molecular weight of benzene is 78. If the concentration of benzene in air is 10 mg/m^3, convert to the units of ppm by multiplying 24.45 x 10 mg/m^3 ÷ 78 = 3.13 ppm.

Note: Sometimes you will see chemical concentrations in air given in concentration per cubic feet (ft^3) instead of concentration per cubic meter (m^3). The conversion from cubic feet to cubic meter and vice versa is as follows: 1 ft^3 = 0.02832 m^3 and 1 m^3 = 35.31 ft^3.

Understanding Units of Measure was developed by Terrie K. Boguski, P.E., Assistant Technical Director of the Center for Hazardous Substance Research (CHSR) at Kansas State University and was funded wholly or in part by Kansas State University. It has been subjected to the Agency's review, and it has been approved for public use. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

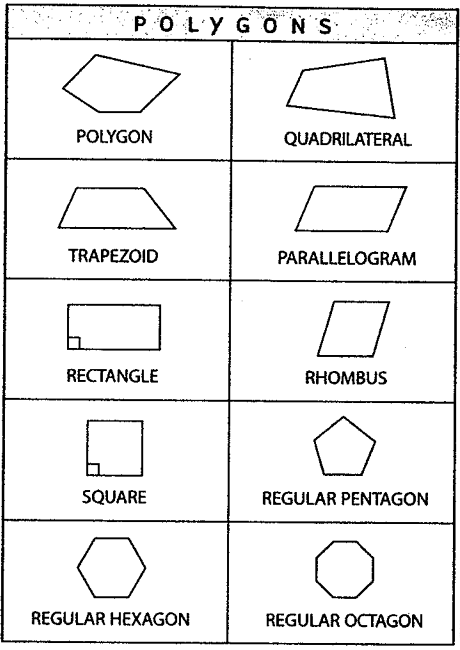
Geometric Shapes / Sizes / Models

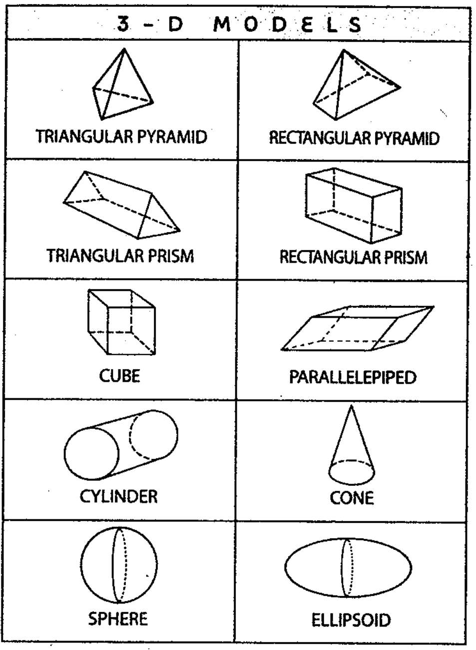





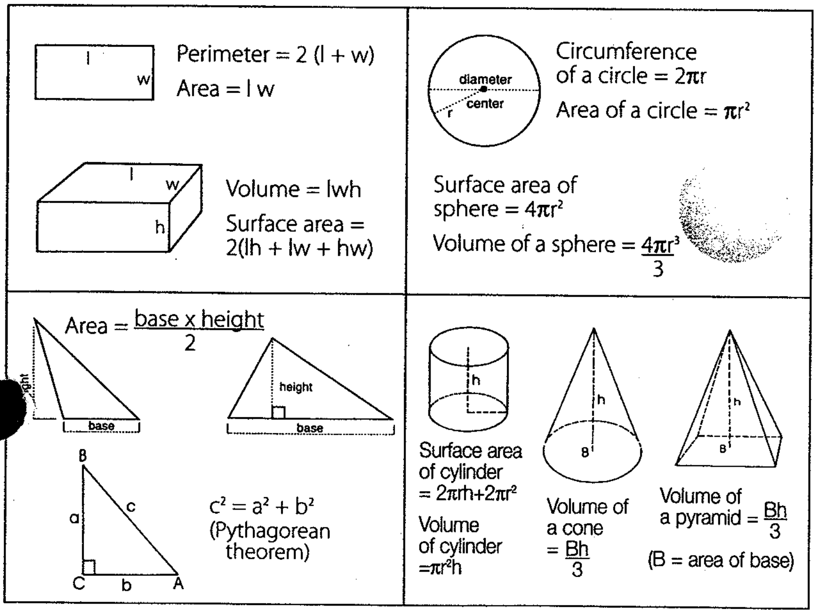
4 CONGRUENCY CASES

1. side, side, side SSS
2. side, angle, side SAS
3. angle, side, angle ASA
4. hypotenuse, side HyS





Measurements



Perimeter = 2 (l + w)
Area = l w

Volume = lwh
Surface area = 2(lh + lw + hw)

Circumference of a circle = $2\pi r$
Area of a circle = πr^2

Surface area of sphere = $4\pi r^2$
Volume of a sphere = $\frac{4\pi r^3}{3}$

Area = $\frac{\text{base x height}}{2}$

$c^2 = a^2 + b^2$ (Pythagorean theorem)

Surface area of cylinder = $2\pi rh+2\pi r^2$
Volume of cylinder = $\pi r^2 h$

Volume of a cone = $\frac{Bh}{3}$

Volume of a pyramid = $\frac{Bh}{3}$
(B = area of base)

Multiplication Chart

	1	2	3	4	5	6	7	8	9	10	11	12
1	1	2	3	4	5	6	7	8	9	10	11	12
2	2	4	6	8	10	12	14	16	18	20	22	24
3	3	6	9	12	15	18	21	24	27	30	33	36
4	4	8	12	16	20	24	28	32	36	40	44	48
5	5	10	15	20	25	30	35	40	45	50	55	60
6	6	12	18	24	30	36	42	48	54	60	66	72
7	7	14	21	28	35	42	49	56	63	70	77	84
8	8	16	24	32	40	48	56	64	72	80	88	96
9	9	18	27	36	45	54	63	72	81	90	99	108
10	10	20	30	40	50	60	70	80	90	100	110	120
11	11	22	33	44	55	66	77	88	99	110	121	132
12	12	24	36	48	60	72	84	96	108	120	132	144
13	13	26	39	52	65	78	91	104	117	130	143	156
14	14	28	42	56	70	84	98	112	126	140	154	168
15	15	30	45	60	75	90	105	120	135	150	165	180

SMART THINKING

Mathematics

Problem Solving Methods

①	GUESS & CHECK	Make a reasonable guess and check it out; if incorrect, try again.
②	LOOK FOR A PATTERN	The key is to find any differences between given pieces of information.
③	WRITE A NUMBER SENTENCE	Take the written information and write it out in math; ignore irrelevant information.
④	MAKE A DIAGRAM OR MODEL	Drawing a picture or a graph may help solve a problem more easily. You could also make a table to sort information.
⑤	WORK BACKWARD	Start at the end of a problem and work your way back to the beginning to find the solution.

Think logically… Act it out if you can… Be a smart estimator… Always test your answer.

Order of Operation / Symbols

①	Do operations within parentheses.	( )
②	Do powers (exponents) and roots.	^{2} $\sqrt{\ }$
③	Do multiplication and division in order from left to right.	x ÷
④	Do addition and subtraction in order from left to right.	+ −

$<$	Is smaller than
$>$	Is greater than
$=$	Is equal to
$\approx$	Approximate
$\leq$	Is smaller or equal
$\geq$	Is greater or equal

Fractions, Decimals, Percentages

3 – numerator
5 – denominator

To ***add*** or ***subtract*** different fractions, first obtain a common denominator:

$$\frac{1}{3}+\frac{2}{5}=\frac{5}{15}+\frac{6}{15}=\frac{11}{15}$$

To ***multiply:***

$$\frac{1}{3}\times\frac{2}{5}=\frac{1\times 2}{3\times 5}=\frac{2}{15}$$

To ***divide,*** multiply the first with the reciprocal of the second fraction:

$$\frac{2}{3}\div\frac{1}{6}=\frac{2}{3}\times\frac{6}{1}=4$$

1	= 1.0	= 100%
1/2	= 0.5	= 50%
1/3	= $0.\overline{3}$	= $33.\overline{3}$%
1/4	= 0.25	= 25%
1/5	= 0.2	= 20%
1/6	= $0.1\overline{6}$	= $16.\overline{6}$%
1/8	= 0.125	= 12.5%
1/9	= $0.\overline{1}$	= $11.\overline{1}$%
1/10	= 0.1	= 10%
1/12	= $0.08\overline{3}$	= $8.\overline{3}$%
2/3	= $0.\overline{6}$	= $66.\overline{6}$%
3/4	= 0.75	= 75%

Squares and Square Roots

n	n^2	$\sqrt{n}$
1	1	1
2	4	1.414
3	9	1.732
4	16	2
5	25	2.236
6	36	2.449

n	n^2	$\sqrt{n}$
7	49	2.646
8	64	2.828
9	81	3
10	100	3.162
11	121	3.317
12	144	3.464

n	n^2	$\sqrt{n}$
15	225	3.873
20	400	4.472
25	625	5
100	10,000	10
1/2	1/4	0.707
1/4	1/16	1/2

Metric System / Conversions

1,000	100	10	1	.1	.01	.001
kilo	hecto	deca		deci	centi	milli
km	hm	dam	m	dm	cm	mm
kg	hg	dag	g	dg	cg	mg
kl	hl	dal	l	dl	cl	ml

Metric system

1 m^2 = 10,000 cm^2
1 hectare (ha) = 10,000 m^2
1 km^2 = 100 ha
1 metric ton (t) = 1,000 kg

English system

1 foot (ft)	= 12 inches (in) 1'	= 12"	
1 yard (yd)	= 3 feet	= 36 inches	
1 mile (mi)	= 1,760 yards	= 5,280 feet	
1 tablespoon (T)	= 3 teaspoons (t)		
1 cup (c)	= 16 T	= 8 fluid ounces (fl oz)	
1 pint (pt)	= 2 c		
1 quart (qt)	= 2 pt	= 4 c	= 32 fl oz
1 gallon (gal)	= 4 qt		
1 ft^2	= 144 in^2		
1 yd^2	= 9 ft^2		
1 acre	= 4,840 yd^2		

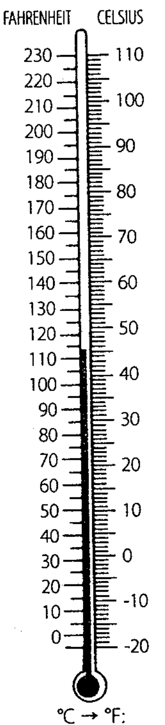
LENGTH / AREA

to go from	to	multiply by
cm	→ in	0.3937
in	→ cm	2.54
m	→ ft	3.2808
ft	→ m	0.3048
km	→ mi	0.6214
mi	→ km	1.609
m^2	→ ft^2	10.76
ft^2	→ m^2	0.0929
km^2	→ mi^2	0.3861
mi^2	→ km^2	2.59

WEIGHT / CAPACITY

to go from	to	multiply by
g	→ oz	0.0353
oz	→ g	28.35
kg	→ lbs	2.2046
lbs	→ kg	0.4536
t	→ T	1.1023
T	→ t	0.9072
ml	→ fl oz	0.0338
fl oz	→ ml	29.575
l	→ gal	0.2642
gal	→ l	3.785

Temperature



°C → °F:
n x 1.8; add 32

°F → °C:
n – 32; multiply by 0.5555

Common Units *used with the International System*

UNITS OF MEAS.	ABBREV.	RELATION	UNITS OF MEAS.	ABBREV.	RELATION
meter*	m	length	degree Celsius	°C	temperature
hectare	ha	area	kelvin	K	thermodynamic temp.
tonne	t	mass	pascal	Pa	pressure, stress
kilogram	kg	mass	joule	J	energy, work
nautical mile	M	distance (navigation)	newton	N	force
knot	kn	speed (navigation)	watt	W	power, radiant flux
liter*	L	volume or capacity	ampere	A	electric current
second	s	time	volt	V	electric potential
hertz	Hz	frequency	ohm	Ω	electric resistance
candela	cd	luminous intensity	coulomb	C	electric charge

Canadian preferred spelling: metre, litre.

FranklinCovey

APPENDIX 7

Table for length conversion

Unit	mm	cm	m	km	in	ft	yd	mi
1 millimeter	1	0.1	0.001	10^{-6}	0.0397	0.00328	0.00109	6.21×10^{-7}
1 centimeter	10	1	0.01	0.0001	0.3937	0.0328	0.0109	6.21×10^{-6}
1 meter	1000	100	1	0.001	39.37	3.281	1.094	6.21×10^{-4}
1 kilometer	10^6	10^5	1000	1	39,370	3281	1093.6	0.621
1 inch	25.4	2.54	0.0254	2.54×10^{-5}	1	0.0833	0.0278	1.58×10^{-5}
1 foot	304.8	30.48	0.3048	3.05×10^{-4}	12	1	0.333	1.89×10^{-4}
1 yard	914.4	91.44	0.9144	9.14×10^{-4}	36	3	1	5.68×10^{-4}
1 mile	1.61×10^6	1.01×10^5	1.61×10^3	1.6093	63,360	5280	1760	1

APPENDIX 8

Table for area conversion

Unit	cm²	m²	km²	ha	in²	ft²	yd²	mi²	ac
1 sq. centimeter	1	0.0001	10^{-10}	10^{-8}	0.155	1.08×10^{-3}	1.2×10^{-4}	3.86×10^{-11}	2.47×10^{-8}
1 sq. meter	10^4	1	10^{-6}	10^{-4}	1550	10.76	1.196	3.86×10^{-7}	2.47×10^{-4}
1 sq. kilometer	10^{10}	10^6	1	100	1.55×10^9	1.076×10^7	1.196×10^6	0.3861	247.1
1 hectare	10^8	10^4	0.01	1	1.55×10^7	1.076×10^5	1.196×10^4	3.861×10^{-3}	2.471
1 sq. inch	6.452	6.45×10^{-4}	6.45×10^{10}	6.45×10^{-8}	1	6.94×10^{-3}	7.7×10^{-4}	2.49×10^{-10}	1.574×10^{-7}
1 sq. foot	929	0.0929	9.29×10^{-8}	9.29×10^{-6}	144	1	0.111	3.587×10^{-8}	2.3×10^{-5}
1 sq. yard	8361	0.8361	8.36×10^{-7}	8.36×10^{-5}	1296	9	1	3.23×10^{-7}	2.07×10^{-4}
1 sq. mile	2.59×10^{10}	2.59×10^6	2.59	259	4.01×10^9	2.79×10^7	3.098×10^6	1	640
1 acre	4.04×10^7	4047	4.047×10^{-3}	0.4047	6.27×10^6	43,560	4840	1.562×10^{-3}	1

APPENDIX 9

Table for volume conversion

Unit	mL	liters	m³	in³	ft³	gal	ac-ft	million gal
1 milliliter	1	0.001	10^{-6}	0.06102	3.53×10^{-5}	2.64×10^4	8.1×10^{-10}	2.64×10^{-10}
1 liter	10^3	1	0.001	61.02	0.0353	0.264	8.1×10^{-7}	2.64×10^{-7}
1 cu. meter	10^6	1000	1	61,023	35.31	264.17	8.1×10^{-4}	2.64×10^{-4}
1 cu. inch	16.39	1.64×10^{-2}	1.64×10^{-5}	1	5.79×10^{-4}	4.33×10^{-3}	1.218×10^{-8}	4.329×10^{-9}
1 cu. foot	28,317	28.317	0.02832	1728	1	7.48	2.296×10^{-5}	7.48×10^6
1 U.S. gallon	3785.4	3.785	3.78×10^{-3}	231	0.134	1	3.069×10^{-6}	10^6
1 acre-foot	1.233×10^9	1.233×10^6	1233.5	75.27×10^6	43,560	3.26×10^5	1	0.3260
1 million gallons	3.785×10^9	3.785×10^6	3785	2.31×10^8	1.338×10^5	10^6	3.0684	1

APPENDIX 10

Table for time conversion

Unit	sec	min	hours	days	years
1 second	1	1.67×10^{-2}	2.77×10^{-4}	1.157×10^{-5}	3.17×10^{-8}
1 minute	60	1	1.67×10^{-2}	6.94×10^{-4}	1.90×10^{-6}
1 hour	360	60	1	4.17×10^{-2}	1.14×10^{-4}
1 day	8.64×10^4	1440	24	1	2.74×10^{-3}
1 year	3.15×10^7	5.256×10^5	8760	365	1

APPENDIX 9.A.
Conversion Tables

Length

Unit	Equivalent[1,2]					
	millimeters	inches	feet	meters	kilometers	miles
millimeters	1	3.937×10^{-2}	3.281×10^{-3}	1×10^{-3}	1×10^{-6}	6.214×10^{-7}
inches	25.4	1	8.33×10^{-2}	2.54×10^{-2}	2.54×10^{-5}	1.578×10^{-5}
feet	304.8	12	1	0.3048	3.048×10^{-4}	1.894×10^{-4}
meters	1,000	39.37	3.281	1	1×10^{-3}	6.214×10^{-4}
kilometers	1×10^{6}	3.937×10^{4}	3,281	1,000	1	0.6214
miles	1.609×10^{6}	6.336×10^{4}	5,280	1,609	1.609	1

Area

Unit	Equivalent[1,2]						
	square inches	square feet	square meters	acres	hectares	square kilometers	square miles
square inches	1	6.944×10^{-3}	6.452×10^{-4}	1.594×10^{-8}	6.452×10^{-8}	6.452×10^{-10}	2.491×10^{-10}
square feet	144	1	9.29×10^{-2}	2.296×10^{-5}	9.29×10^{-9}	9.29×10^{-8}	3.587×10^{-8}
square meters	1.550	10.76	1	2.471×10^{-4}	1×10^{-4}	1×10^{-6}	3.861×10^{-7}
acres	6.273×10^{6}	4.356×10^{4}	4,047	1	0.4047	4.047×10^{-3}	1.563×10^{-3}
hectares	1.55×10^{7}	1.076×10^{5}	1×10^{4}	2.471	1	0.01	3.861×10^{-3}
square kilometers	1.55×10^{9}	1.076×10^{7}	1×10^{6}	247.1	100	1	0.3861
square miles	4.014×10^{9}	2.788×10^{7}	2.59×10^{6}	640	259	2.59	1

Volume

Unit	Equivalent[1,2]						
	cubic inches	liters	gallons	cubic feet	cubic yards	cubic meters	acre-ft
cubic inches	1	1.639×10^{-2}	4.329×10^{-3}	5.787×10^{-4}	2.143×10^{-5}	1.639×10^{-5}	1.329×10^{-8}
liters	61.02	1	0.2642	3.531×10^{-2}	1.308×10^{-3}	0.001	8.106×10^{-7}
gallons	231.0	3.785	1	0.1337	4.951×10^{-3}	3.785×10^{-3}	3.068×10^{-6}
cubic feet	1,728	28.32	7.481	1	3.704×10^{-2}	2.832×10^{-3}	2.296×10^{-5}
cubic yards	4.666×10^{4}	764.6	202.0	27	1	0.7646	6.198×10^{-4}
cubic meters	6.102×10^{4}	1,000	264.2	35.31	1.308	1	8.106×10^{-4}
acre-ft	7.527×10^{7}	1.233×10^{6}	3.259×10^{5}	4.356×10^{4}	1,613	1,233	1

Discharge (flow rate, volume/time)

Unit	Equivalent[1,2]				
	gallons per minute	liters per second	acre-feet per day	cubic feet per second	cubic meters per day
gallons per minute	1	6.309×10^{-2}	4.419×10^{-3}	2.228×10^{-3}	5.45
liters per second	15.85	1	7.005×10^{-2}	3.531×10^{-2}	86.4
acre-feet per day	226.3	14.28	1	0.5042	1,234
cubic feet per second	448.8	28.32	1.983	1	2,447
cubic meters per day	1.369×10^{9}	8.64×10^{7}	6.051×10^{6}	3.051×10^{6}	1

Appendix 9.A. Continued

Velocity

Unit	Equivalent[1,2]				
	feet per day	kilometers per hour	feet per second	miles per hour	meters per second
feet per day	1	1.27×10^{-5}	1.157×10^{-5}	7.891×10^{-6}	3.528×10^{-6}
kilometers per hour	7.874×10^{4}	1	0.9113	0.6214	0.2778
feet per second	8.64×10^{4}	1.097	1	0.6818	0.3048
miles per hour	1.267×10^{5}	1.609	1.467	1	0.447
meters per second	2.835×10^{5}	3.6	3.281	2.237	1

Mass

Unit	Equivalent[1,2]							
	ounce	pound	kilogram	metric slug	slug	short ton	metric ton	long ton
ounce	1	6.25×10^{-2}	2.835×10^{-2}	2.891×10^{-3}	1.943×10^{-3}	3.125×10^{-5}	2.835×10^{-5}	2.79×10^{-5}
pound	16	1	0.4536	4.625×10^{-2}	3.108×10^{-2}	5×10^{-4}	4.536×10^{-4}	4.464×10^{-4}
kilogram	35.28	2.205	1	0.102	6.852×10^{-2}	1.102×10^{-3}	0.001	9.842×10^{-4}
metric slug	345.9	21.62	9.807	1	0.6721	92.51	9.807×10^{-3}	9.651×10^{-3}
slug	514.7	32.17	14.59	1.49	1	62.17	1.459×10^{-2}	1.436×10^{-2}
short ton	3.2×10^{4}	2,000	907.2	92.51	62.16	1	0.907	0.8929
metric ton	3.528×10^{4}	2,205	1,000	102	68.52	1.103	1	0.9842
long ton	3.584×10^{4}	2,240	1,016	103.7	69.63	1.12	1.016	1

Force

Unit	Equivalent[1,2]			
	dyne	newton	$\text{pound}_{\text{force}}$	$\text{kilogram}_{\text{force}}$
dynes	1	1×10^{-5}	2.248×10^{-6}	1.02×10^{-6}
newtons	1×10^{5}	1	0.2248	0.102
$\text{pound}_{\text{force}}$	4.448×10^{5}	4.448	1	0.4536
$\text{kilogram}_{\text{force}}$	9.807×10^{5}	9.807	2.205	1

Density

Unit	Equivalent[1,2]				
	pounds per cubic inch	pounds per cubic feet	pounds per gallon	grams per cubic centimeter	grams per liter
pounds per cubic inch	1	1,728	231	27.68	2.768×10^{4}
pounds per cubic feet	5.787×10^{-4}	1	0.1337	1.6×10^{-2}	16.02
pounds per gallon	4.33×10^{-3}	7.481	1	0.1198	119.8
grams per cubic centimeter	3.61×10^{-2}	62.43	8.345	1	1,000
grams per liter	3.61×10^{-5}	6.24×10^{-2}	8.35×10^{-3}	0.001	1

TABLE 4.1 English and SI Units

1 N = 1 Kg·m/sec²

Parameter	English Unit	SI Unit	Conversion Factor	Dimensional Formula
Force	pound (lb)	newton (N)	1 lb = 4.448 N	ML/T^2
Mass	slug	kilogram (kg)	1 slug = 14.594 kg	M
Length	foot (ft)	meter (m)	1 ft = 0.3048 m	L
Time	second (s)	second	1 s = 1 s	T
Density	slug/ft³	kg/m³	1 slug/ft³ = 515.4 kg/m³	M/L^3
Specific weight	lb/ft³	N/m³	1 lb/ft³ = 157.1 N/m³	M/L^2T^2
Pressure	lb/ft²	N/m²	1 lb/ft² = 47.88 N/m²	M/LT^2
Dynamic viscosity	lb-s/ft²	N·s/m²	1 lb-s/ft² = 47.88 N·s/m²	M/LT
Bulk modulus	lb/ft²	N/m²	1 lb/ft² = 47.88 N/m²	M/LT^2

g = Acceleration due to Gravity = 9.8 m/sec²

Equations for areas and volumes

Circumference of circle = 3.1416 × dia = 6.2832 × radius
Area of circle = 0.7854 × (dia)² = 3.1416 × (radius)²
Area of sphere = 3.1416 × (dia)²
Volume of sphere = 0.5236 × (dia)³
Area of triangle = 0.5 × base × height
Area of trapezoid = 0.5 × sum of the two parallel sides × height
Area of square, rectangle, or parallelogram = base × height
Volume of pyramid = area of base × 1/3 height
Volume of cone = 0.2618 × (dia of base)² × height
Volume of cylinder = 0.7854 × height × (dia)²

Pressure

Unit	Equivalent[1,2]										
	pounds per square inch	pounds per square feet	atmospheres	kilograms per square centimeter	kilograms per square meter	inches of water (68°F)[3]	feet of water (68°F)[3]	inches of mercury (32°F)[4]	millimeters of mercury (32°F)[4]	bars	kilo Pascals
pounds per square inch	1	144	6.805×10^{-2}	7.031×10^{-2}	703.1	27.73	2.311	2.036	51.72	6.895×10^{-2}	6.895
pounds per square feet	6.945×10^{-3}	1	4.73×10^{-4}	4.88×10^{-4}	4.882	0.1926	1.605×10^{-2}	1.414×10^{-2}	0.3591	4.79×10^{-4}	4.79×10^{-2}
atmospheres	14.7	2,116	1	1.033	1.033×10^{4}	407.5	33.96	29.92	760	1.013	101.3
kilograms per square centimeter	14.22	2,048	0.9678	1	1×10^{4}	394.4	32.87	28.96	735.6	0.9807	98.07
kilograms per square meter	1.422×10^{-3}	0.2048	9.678×10^{-5}	0.001	1	3.944×10^{-2}	3.287×10^{-3}	2.896×10^{-3}	7.356×10^{-2}	9.807×10^{-5}	9.807×10^{-3}
inches of water (68°F)[3]	3.609×10^{-2}	5.197	2.454×10^{-3}	2.53×10^{-3}	25.38	1	8.333×10^{-2}	7.343×10^{-2}	1.865	2.49×10^{-3}	0.249
feet of water (68°F)[3]	0.4328	62.32	2.945×10^{-2}	3.043×10^{-2}	304.3	12	1	0.8812	22.38	2.984×10^{-2}	2.984
inches of mercury (32°F)[4]	0.4912	70.73	3.342×10^{-2}	3.453×10^{-2}	345.3	13.62	1.135	1	25.4	3.386×10^{-2}	3.386
millimeters of mercury (32°)[4]	1.934×10^{-2}	2.785	1.316×10^{-3}	1.36×10^{-3}	13.6	0.5362	4.468×10^{-2}	3.937×10^{-2}	1	1.333×10^{-3}	0.1333
bars	14.5	2,089	0.9869	1.02	1.02×10^{4}	402.2	33.51	29.53	750.1	1	100
kilo Pascals	0.145	20.89	9.869×10^{-3}	1.02×10^{-2}	102	4.022	0.3351	0.2953	7.501	0.01	1

APPENDIX 14

Absolute density and absolute viscosity of water

Temperature (°C)	Density (kg/m³)	Density (g/cm³)	Viscosity (g/s·cm)
0	999.841	0.999841	0.017921
1	999.900	0.999900	0.017313
2	999.941	0.999941	0.016728
3	999.965	0.999965	0.016191
4	999.973	0.999973	0.015674
5	999.965	0.999965	0.015188
6	999.941	0.999941	0.014728
7	999.902	0.999902	0.014284
8	999.849	0.999849	0.013860
9	999.781	0.999781	0.013462
10	999.700	0.999700	0.013077
11	999.605	0.999605	0.012713
12	999.498	0.999498	0.012363
13	999.377	0.999377	0.012028
14	999.244	0.999244	0.011709
15	999.099	0.999099	0.011404
16	998.943	0.998943	0.011111
17	998.774	0.998774	0.010828
18	998.595	0.998595	0.010559
19	998.405	0.998405	0.010299
20	998.203	0.998203	0.010050
21	997.992	0.997992	0.009810
22	997.770	0.997770	0.009579
23	997.538	0.997538	0.009358
24	997.296	0.997296	0.009142
25	997.044	0.997044	0.008937
26	996.783	0.996783	0.008737
27	996.512	0.996512	0.008545
28	996.232	0.996232	0.008360
29	995.944	0.995944	0.008180
30	995.646	0.995646	0.008007
35	994.029	0.994029	0.007225
40	992.214	0.992214	0.006560
45	990.212	0.990212	0.005988
50	988.047	0.988047	0.005494

Source: *Handbook of Chemistry and Physics* (Cleveland, Ohio: CRC Publishing Company, 1986).

NOTATION

a	Acceleration
A	Area
A_t	Cross-sectional area of a falling-head tube
A_c	Cross-sectional area of a permeameter sample chamber
b	Aquifer thickness
c	Shape factor
c_u	Uniformity coefficient
d	Grain size
D	Distance
d_t	Inside diameter of falling-head tube
d_c	Inside diameter of a permeameter sample chamber
F	Force
g	Gravitational constant
h	Head
j	An exponent
K	Hydraulic conductivity
K_h	Horizontal hydraulic conductivity
K_i	Intrinsic permeability
K_v	Vertical hydraulic conductivity
L	Length
m	Mass
n	Porosity
P	Pressure
q	Flux
Q	Discharge (rate)
S	Storativity
S_s	Specific storage
S_r	Specific retention
S_y	Specific yield
T	Transmissivity
w	Weight
V	Volume
V_v	Volume of voids
V_w	Volume of water
W	Work
α	Compressibility of aquifer skeleton
β	Compressibility of water
γ	Specific weight
Δh	Decline in head
ρ	Density
ρ_b	Bulk density
ρ_d	Mineral particle density
ρ_w	Density of water

′	44°		′	′	44°		′	′	44°		′
	Tang	Cotang			Tang	Cotang			Tang	Cotang	
0	.96569	1.03553	60	20	.97700	1.02355	40	40	.98843	1.01170	20
1	.96625	1.03493	59	21	.97756	1.02296	39	41	.98901	1.01112	19
2	.96681	1.03433	58	22	.97813	1.02236	38	42	.98958	1.01053	18
3	.96738	1.03372	57	23	.97870	1.02176	37	43	.99016	1.00994	17
4	.96794	1.03312	56	24	.97927	1.02117	36	44	.99073	1.00935	16
5	.96850	1.03252	55	25	.97984	1.02057	35	45	.99131	1.00876	15
6	.96907	1.03192	54	26	.98041	1.01998	34	46	.99189	1.00818	14
7	.96963	1.03132	53	27	.98098	1.01939	33	47	.99247	1.00759	13
8	.97020	1.03072	52	28	.98155	1.01879	32	48	.99304	1.00701	12
9	.97076	1.03012	51	29	.98213	1.01820	31	49	.99362	1.00642	11
10	.97133	1.02952	50	30	.98270	1.01761	30	50	.99420	1.00583	10
11	.97189	1.02892	49	31	.98327	1.01702	29	51	.99478	1.00525	9
12	.97246	1.02832	48	32	.98384	1.01642	28	52	.99536	1.00467	8
13	.97302	1.02772	47	33	.98441	1.01583	27	53	.99594	1.00408	7
14	.97359	1.02713	46	34	.98499	1.01524	26	54	.99652	1.00350	6
15	.97416	1.02653	45	35	.98556	1.01465	25	55	.99710	1.00291	5
16	.97472	1.02593	44	36	.98613	1.01406	24	56	.99768	1.00233	4
17	.97529	1.02533	43	37	.98671	1.01347	23	57	.99826	1.00175	3
18	.97586	1.02474	42	38	.98728	1.01288	22	58	.99884	1.00116	2
19	.97643	1.02414	41	39	.98786	1.01229	21	59	.99942	1.00058	1
20	.97700	1.02355	40	40	.98843	1.01170	20	60	1.00000	1.00000	0
′	Cotang	Tang	′	′	Cotang	Tang	′	′	Cotang	Tang	′
	45°				45°				45°		

APPENDIX 8. EQUIVALENCE OF SOME UNITS OF WEIGHT AND MEASURE

Underlined figures are exact; others are rounded off. Condensed from Letter Circular 1035 (Jan., 1960) of the U.S. Department of Commerce, National Bureau of Standards, Washington 25, D.C.

1 in. = 0.08333 ft; 0.02778 yd; 2.54 cm.
1 ft = 12 in.; 0.6061 rods; 0.3048 m; 0.0001894 mi
1 yd = 3 ft; 0.9144 m; 0.1818 rods; 0.0005682 mi
1 m = 1000 mm; 100 cm; 10 decimeters 0.1 dekameters; 0.01 hectometers; 0.001 km
1 m = 39.37 in.; 3.2808 ft; 1.0936 yd; 0.0006214 mi
1 fathom = 6 ft; 1.8288 m
1 rod = 198 in.; 16.5 ft; 5.5 yd
1 chain = 100 links; 66 ft; 0.0125 mi; 20.117 m;
1 mi = 5280 ft; 1760 yd; 320 rods; 1609.344 m;
1 nautical mi = 6076.1 ft; 1852 m
1 sq in. = 6.4516 sq cm; 0.00694 sq ft
1 sq ft = 144 sq in.; 0.1111 sq yd; 0.0929 sq m
1 sq yd = 1296 sq in.; 9 sq ft; 0.8361 sq m
1 sq m = 1551 sq in.; 10.76 sq ft; 1.196 sq yd
1 acre = 43560 sq ft; 4840 sq yd; 0.405 hectares; 0.00156 sq mi
1 sq mi = 640 acres; 259 hectares
1 cu cm = 0.0610 cu in.; 0.000001 cu m
1 cu in. = 0.0005787 cu ft; 16.387 cu cm
1 cu ft = 1728 cu in.; 0.03704 cu yd; 0.0283 cu m; 7.480 gal (U.S.)
1 cu yd = 46656 cu in.; 27 cu ft; 0.7645 cu m
1 cu m = 35.315 cu ft; 1.3079 cu yd
1 gal (U.S.) = 231 cu in; 128 fl oz; 0.1337 cu ft; 3.785 liters
1 liter = 61.025 cu in.; 0.2642 gal (U.S.); 0.0353 cu ft
1 acre ft = 43560 cu ft; 325851 gal (U.S.); 1233.5 cu m
1 oz (avoir.) = 437.5 grains; 28.350 grams; 0.0625 lbs (avoir.)
1 gram = 15.432 grains; 0.03527 oz (avoir.); 0.002205 lbs (avoir.)
1 short (net) ton = 2000 lbs; 0.9072 metric ton; 0.8929 long (gross) ton

Conversions of Hydraulic Conductivity, Intrinsic Permeability and Transmissivity

A. Hydraulic Conductivity, K [L/T], and Intrinsic Permeability, k [L^2]

	K								*k*		
	cm/s	*m/s*	*m/day*	*ft/s*	*ft/day*	*ft/yr*	*USgpd/ft^2*	*UKgpd/ft^2*	*darcy*	*cm^2*	*ft^2*
cm/s	1	1.00E-2	8.64E2	3.28E-2	2.83E3	1.03E6	2.12E4	1.77E4	1.16E3	1.15E-5	1.24E-8
m/s	1.00E2	1	8.64E4	3.28	2.83E5	1.03E8	2.12E6	1.77E6	1.16E5	1.15E-3	1.24E-6
m/day	1.16E-3	1.16E-5	1	3.80E-5	3.28	1.20E3	2.45E1	2.04E1	1.35	1.33E-8	1.43E-11
ft/s	3.05E1	.305	2.63E4	1	8.64E4	3.15E7	6.46E5	5.38E5	3.55E4	3.50E-4	3.77E-7
ft/day	3.53E-4	3.53E-6	.305	1.16E-5	1	3.65E2	7.48	6.23	.411	4.06E-9	4.36E-12
ft/yr	9.66E-7	9.66E-9	8.35E-4	3.17E-8	2.74E-3	1	2.05E-2	1.71E-2	1.13E-3	1.11E-11	1.20E-14
USgpd/ft^2	4.72E-5	4.72E-7	4.07E-2	1.55E-6	.134	4.88E1	1	.833	5.49E-2	5.42E-10	5.83E-13
UKgpd/ft^2	5.66E-5	5.66E-7	4.89E-2	1.86E-6	.161	5.86E1	1.20	1	6.60E-2	6.51E-10	7.01E-13
darcy	8.58E-4	8.58E-6	7.42E-1	2.82E-5	2.43	8.88E2	1.82E1	1.52E1	1	9.87E-9	1.06E-11
cm^2	8.70E4	8.70E2	7.51E7	2.85E3	2.47E8	9.00E10	1.84E9	1.54E9	1.01E8	1	1.08E-3
ft^2	8.08E7	8.08E5	6.98E10	2.65E6	2.29E11	8.36E13	1.71E12	1.43E12	9.41E10	9.29E2	1

The relation between units of K and k is temperature dependent: these factors are for 60° F.

B. Transmissivity [L^2/T]

	m^2/s	*m^2/min*	*m^2/day*	*ft^2/s*	*ft^2/day*	*USgpd/ft*	*UKgpd/ft*
m^2/s	1	6.00E1	8.64E4	1.08E1	9.30E5	6.96E6	5.79E6
m^2/min	1.67E-2	1	1.44E3	1.79E-1	1.55E4	1.16E5	9.65E4
m^2/day	1.16E-5	6.94E-4	1	1.25E-4	1.08E1	8.05E1	6.70E1
ft^2/s	9.29E-2	5.57	8.03E3	1	8.64E4	6.46E5	5.38E5
ft^2/day	1.08E-6	6.45E-5	9.29E-2	1.16E-5	1	7.48	6.23
USgpd/ft	1.44E-7	8.62E-6	1.24E-2	1.55E-6	1.34E-1	1	.833
UKgpd/ft	1.73E-7	1.04E-5	1.49E-2	1.86E-6	1.61E-1	1.20	1

Enter either table at the left with the given unit: move right to the column of the unit to be derived; read the conversion factor as a multiplier.
Example: to convert 2.1 ft/day (hydraulic conductivity) to cm/s: 2.1 ft/day × 3.53E-4 = 7.4E-4 cm/s.
Conversion factors are given in FORTRAN/BASIC notation; thus 3.53E-4 = 3.53×10^{-4}.

Vi

ENGLISH-METRIC UNIT CONVERSION TABLE

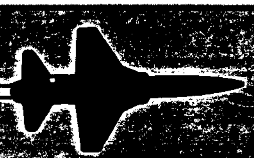
To convert A to B, multiply A by C; To convert B to A, divide B by C

A	B	C
Length —		
inch	meter	2.540E−2
feet	meter	.3048
yard	meter	.9144
mile	kilometer	1.609
inch	centimeter	2.540
Area —		
sq inch	sq centimeter	6.452
sq feet	sq meter	9.290E−2
sq yard	sq meter	.8361
sq mile	sq kilometer	2.590
acre	sq kilometer	4.047E−3
acre	hectare	.4047
Volume —		
cu feet	cu meter	2.832E−2
cu yard	cu meter	.7646
cu inch	cu centimeter	1.639E1
quart	liter	.9464
gallon	liter	3.785
gallon (UK)	liter	4.546
barrel (petr.)	liter	1.590E2
acre-feet	cu meter	1.234E3
million gal	cu meter	3.785E3
gallon (UK)	gallon (US)	1.200
Mass —		
pound (lb)	kilogram	.4536
ounce	gram	2.835E1
ton, short	tonne (metric)	.9072
ton, long	tonne	1.016
Velocity and gradient —		
feet/sec	meter/sec	.3048
mile/hour	meter/sec	.4470
feet/mile	meter/km	.1894
Flow rate —		
gal/min	liter/sec	6.309E−2
gal/min	cu meter/day	5.300
gal (UK)/min	liter/sec	7.577E−2
10^6 gal/day	liter/sec	4.381E1
10^6 gal/day	cu meter/day	3.785E−3
cu ft/sec (cfs)	liter/sec	2.832E1
acre-feet/day	liter/sec	1.458E−1
gal/day	acre-feet/yr	1.120E−3

A	B	C
Hydraulic conductivity —		
gal/day/ft^2	cm/sec	4.716E−5
gal/day/ft^2	ft/day	.1337
gal/day/ft^2	meter/day	4.075E−2
gal (UK)/day/ft^2	meter/day	4.893E−2
ft/yr	cm/sec	9.665E−7
ft/yr	meter/day	8.351E−4
darcy (atm/cm)	cm/sec	8.584E−4
darcy	ft/day	2.433
darcy	meter/day	.7416
Transmissivity —		
gal/day/ft	sq meter/day	1.242E−2
gal (UK)/day/ft	sq meter/day	1.492E−2
sq ft/sec	sq meter/day	8.027E3
sq ft/day	sq meter/day	9.290E−2
Force and pressure —		
pound (f)	newton	4.448
poundal	newton	.1383
pounds/sq in.	pascal	6.895E3
lb/sq ft	pascal	4.788E1
poundal/sq ft	pascal	1.488
atmosphere	pascal	1.013E5
inches of Hg	pascal	3.386E3
millibar	pascal	1.000E2
psi	kg/cm^2	7.031E−2
ft of H_2O (4°C)	psi	.4335
Work, energy and heat —		
horsepower (US)	horsepower (CV)	1.014
horsepower (US)	kW-hr	.7457
ft-lb/sec	kW	1.356E−3
BTU	kW-hr	2.930E−4
gpm/100′ lift	kW	1.884E−2
ft-lb	joule	1.356
ft-poundal	joule	4.214E−2
BTU	joule	1.055E−3
calorie	joule	4.187
Temperature —		
Fahrenheit	Celsius	5(F−32)/9
Celsius	Fahrenheit	1.8(C)+32
Kelvin	Celsius	K−273.2

Notes: (1) The "E" notation indicates exponentiation: $2.540\text{E—}2 = 2.540 \cdot 10^{-2}$. (2) Unless otherwise noted, all gallons are U.S. gallons. (3) The darcy is a unit of permeability (L^2), not of hydraulic conductivity (L/T). (4) A Newton (force) = $kg \cdot m/s^2$; A Pascal (pressure) = $kg/m \cdot s^2$; Joule (energy) = $kg \cdot m^2/s^2$; each is a unit in SI. (5) Under "Temperature," entries are formulae, not multipliers.

Handy Scientific Data



PHYSICS

FORMULAS

- **Composition of Forces**

The resultant of two forces acting at an angle upon a given point is equal to the diagonal of a parallelogram of which the two force vectors are sides. The equilibrant equals the magnitude of the resultant, but acts in the opposite direction.

- **Accelerated Motion**

$$v = at, \text{ or } v = gt$$

v is final velocity; a is acceleration, or g is acceleration due to gravity; t is time

- **Accelerated Motion**

$$s = \tfrac{1}{2}at^2 \text{ or } s = \tfrac{1}{2}gt^2$$

s is total distance; a is acceleration, or g is acceleration due to gravity; t is time

- **Accelerated Motion**

$$v = \sqrt{2as}, \text{ or } v = \sqrt{2gs}$$

v is final velocity; a is acceleration, or g is acceleration due to gravity; s is total distance

- **Newton's Second Law of Motion**

$$F = ma$$

F is force; m is mass; a is acceleration

- **Impulse and Momentum**

$$Ft = mv$$

F is force; t is time; the product Ft is impulse; m is mass; v is velocity; the product mv is momentum

- **Centrifugal Force**

$$\text{Centrifugal Force} = \frac{mv^2}{r}$$

m is mass; v is velocity; r is radius of path

- **Work**

$$W = Fs$$

W is work; F is force; s is distance

- **Potential Energy**

$$P.E. = mgh$$

P.E. is potential energy; m is mass; g is acceleration due to gravity; h is vertical distance

- **Kinetic Energy**

$$K.E. = \tfrac{1}{2}mv^2$$

K.E. is kinetic energy; m is mass; v is velocity

PHYSICAL CONSTANTS

$C = 2.9979 \times 10^{8}$ m/s
$G = 6.6720 \times 10^{-11}$ $m^3 \bullet s^{-2} \bullet kg^{-1}$
$e = 1.6022 \times 10^{-19}$ C
$e/m_e = 1.7588 \times 10^{11}$ $C \bullet kg^{-1}$
$F = 9.6485 \times 10^{4}$ $C \bullet mol^{-1}$
$V_m = 22.4138 \times 10^{-3} m^3 \bullet mol^{-1}$
$h = 6.6262 \times 10^{-34} J \bullet s$
$R = 8.3144\ J \bullet mol^{-1} \bullet k^{-1}$
$N_A = 6.0220 \times 10^{23}$ mol^{-1}
Atomic Mass Unit $\mu = 1.6606 \times 10^{-27}$ kg
$M_e = 9.1094 \times 10^{-31}$ kg
1 Kilogram Calorie (Nutrition Calorie) = 4.1868 Kilojoules
1 BTU = 1.0551kJ

RELATIONS BETWEEN COMMON UNITS

LENGTH

1 in = 2.540 cm
1 ft = 30.48 cm
1 micron (μ) = 0.000001 m = 0.001 mm = 10^{-4} cm
1 millionth micron ($\mu\mu$) = 10^{-10}
1 Angstrom Unit = 10^{8} cm

VOLUME

1 Liter = 1000 cm^3 = 61.024 in^3 = 1.05671 qt.

MASS

1 lb = 453.59 g.
1 kg = 2.2046 lb

ANGLES

1 circumference = 360° = 2π radians
1 radian = 57.2958°

DENSITY

1 gr / cm^3 = 62.4 lb / ft^3

WORK OR ENERGY

1 ft-lb = 1.356×10^{7} ergs
1 joule = 10^{7} ergs
1 gr cal = 4.186×10^{7} ergs
1 B.T.U. = 777.8 ft-lb = 252.2 g cal

POWER

1 H.P. = 33,000 ft lb / min
= 550 ft lb / sec = 746 watts
1 watt = 1 joule/second

ELECTRICAL UNITS

1 ampere = 10^{-1} ab amps = 3×10^{9} ESU
1 volt = 10^{8} EMU = $\tfrac{1}{3} \times 10^{-2}$ ESU
1 coulomb = 10^{-1} EMU = 3×10^{9} ESU
1 ohm = 10^{9} EMU = $\tfrac{1}{9} \times 10^{-11}$ ESU
1 farad = 10^{-9} EMU = 9×10^{11} ESU
1 henry = 10^{9} EMU = $\tfrac{1}{9} \times 10^{11}$ ESU

GET AN ASSOCIATE DEGREE THROUGH THE COMMUNITY COLLEGE OF THE AIR FORCE. You can go to college while in the Air Force drawing full salary and benefits. It's the nation's first military-operated education institution empowered to grant enlisted members a two-year Associate in Applied Science Degree. The college awards the degree' in more than 80 technical specialties. There is no registration fee, and the college provides a worldwide transcript service to record the member's various civilian and military course completions.

THE AIR FORCE RESERVE is also available to the individual who wants to serve on a part time basis. The Reserve offers many training opportunities as well as an excellent weekend salary. You meet one weekend a month and complete two weeks of annual training each year. It's one of the finest part time jobs in America. Your nearest Air Force Reserve unit can furnish you with information.

AIR FORCE ROTC COLLEGE SCHOLARSHIPS are available to qualified high school seniors. Applications for scholarships must be in by December 15 of your senior year. Your high school counselor has the details.

THE AIR FORCE JUNIOR ROTC PROGRAM, which is available in many high schools, normally begins with the sophomore year. The program offers a wide range of aviation subjects, including modern aircraft, space operations, principles of flight, propulsion, and navigation. It's a great program for high school students. See your high school counselor for details.

THE AIR FORCE ACADEMY is one of the nation's finest colleges, and is another fine Air Force opportunity. Each year, the Air Force offers highly qualified high school seniors an opportunity to compete for an appointment to the Academy. Applications should be in by January 31 of your junior year. Your high school counselor also has details about this program. Or, you may write to the USAF Academy, Colorado Springs, CO. 80840

CONSIDER THE AIR FORCE when you consider your future. It offers you some of of the finest technical training in the nation, educational opportunities that are hard to beat, and a good salary. Check it out now. You can sign up in the Delayed Enlistment Program 270 days before you graduate. You'll be glad you did.

For more information or the location of your nearest recruiter, call toll free 800-447-4700 (in Illinois call 800-322-4400)

CHEMISTRY

SYMBOLS OF SOME PARTICLES

electron	$_{-1}e^{0}$	deuteron	$_{1}H^{2}$
neutron	$_{0}n^{1}$	triton	$_{1}H^{3}$
proton	$_{1}H^{1}$	alpha particle	$_{2}He^{4}$

OXIDATION STATE OF SOME RADICALS

CH_3COO	ClO_4	H_2PO_4	NO_3
$CO_3^{=}$	$Cr_2O_7^{=}$	H_3O^{+}	OH
$C_2O_4^{=}$	HCO_3	Hg_2^{++}	PO_3
ClO	$HPO_4^{=}$	MnO_4	PO_4
ClO_2	HSO_3	NH_4^{+}	$SO_3^{=}$
ClO_3	HSO_4	NO_2	SO_4

PERIODIC TABLE OF THE ELEMENTS

Atomic weights conform to the 1961 values of the Commission on Atomic Weights.

KEY
Atomic Mass (Weight) — 12.01115
Symbol — C
Atomic Number — 6

GROUPS

Transition Elements

Period	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	0
1	1.00797 H 1																1.00797 H 1	4.0026 He 2
2	6.939 Li 3	9 0122 Be 4											10 811 B 5	12.01115 C 6	14.0067 N 7	15.9994 O 8	18.9984 F 9	20.183 Ne 10
3	22.9898 Na 11	24.312 Mg 12											26.9815 Al 13	28.086 Si 14	30.9738 P 15	32.064 S 16	35.453 Cl 17	39.948 Ar 18
4	39.102 K 19	40.08 Ca 20	44.956 Sc 21	47 90 Ti 22	50.942 V 23	51.996 Cr 24	54.9380 Mn 25	55.847 Fe 26	58.9332 Co 27	58.71 Ni 28	63.54 Cu 29	65.37 Zn 30	69.72 Ga 31	72.59 Ge 32	74.9216 As 33	78.96 Se 34	79.909 Br 35	83.80 Kr 36
5	85.47 Rb 37	87.62 Sr 38	88.905 Y 39	91.22 Zr 40	92 906 Nb 41	95.94 Mo 42	(99) Tc 43	101.07 Ru 44	102.905 Rh 45	106.4 Pd 46	107.870 Ag 47	112.40 Cd 48	114.82 In 49	118.69 Sn 50	121 75 Sb 51	127.60 Te 52	126.9044 I 53	131.30 Xe 54
6	132.905 Cs 55	137.34 Ba 56	138.91 La 57	178.49 Hf 72	180.948 Ta 73	183.85 W 74	186.2 Re 75	190.2 Os 76	192 2 Ir 77	195.09 Pt 78	196.967 Au 79	200.59 Hg 80	204.37 Tl 81	207.19 Pb 82	208.980 Bi 83	(210) Po 84	(210) At 85	(222) Rn 86
7	(223) Fr 87	(226) Ra 88	(227) Ac 89															

Numbers in parentheses are mass numbers of most tables or most common isotope.

Lanthanide Series

140.12 Ce 58	140 907 Pr 59	144.24 Nd 60	(147) Pm 61	150.35 Sm 62	151.96 Eu 63	157.25 Gd 64	158.924 Tb 65	162.50 Dy 66	164.930 Ho 67	167.26 Er 68	168.934 Tm 69	173.04 Yb 70	174.97 Lu 71

Actinide Series

232.038 Th 90	(231) Pa 91	238.03 U 92	(237) Np 93	(242) Pu 94	(243) Am 95	(247) Cm 96	(247) Bk 97	(249) Cf 98	(254) Es 99	(253) Fm 100	(256) Md 101	(254) No 102	(257) Lw 103

STANDARD OXIDATION POTENTIALS

Ionic Concentrations 1 molal in water at 25°C

Half cell Reaction	E° (volts)
$Li = Li^{+} + e$	3.05
$Rb = Rb^{+} + e^{-}$	2.93
$K = K^{+} + e^{-}$	2.93
$Cs = Cs^{+} + e^{-}$	2.92
$Ba = Ba^{++} + 2e^{-}$	2.90
$Sr = Sr^{++} + 2e^{-}$	2.89
$Ca = Ca^{++} + 2e^{-}$	2.87
$Na = Na^{+} + e^{-}$	2.71
$Mg = Mg^{++} + 2e^{-}$	2.37
$Be = Be^{++} + 2e^{-}$	1.85

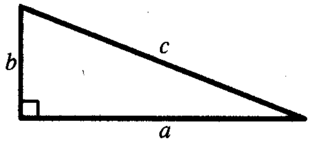
Half cell Reaction	E° (volts)
$Al = Al^{+++} + 3e^{-}$	1.66
$Mn = Mn^{++} + 2e^{-}$	1.18
$Zn = Zn^{++} + 2e^{-}$	0.76
$Cr = Cr^{+++} + 3e^{-}$	0.74
$Fe = Fe^{++} + 2e^{-}$	0.44
$Cd = Cd^{++} + 2e^{-}$	0.40
$Co = Co^{++} + 2e^{-}$	0.28
$Ni = Ni^{++} + 2e^{-}$	0.25
$Sn = Sn^{++} + 2e^{-}$	0.14
$Pb = Pb^{++} + 2e^{-}$	0.13

Half cell Reaction	E° (volts)
$H_2 = 2H^{+} + 2e^{-}$	0.00
$Sn^{++} = Sn^{++++} + 2e^{-}$	—0.15
$Cu^{+} = Cu^{++} + e^{-}$	—0.15
$Cu = Cu^{++} + 2e^{-}$	—0.34
$2I = I_2 + 2e^{-}$	—0.53
$Fe^{++} = Fe^{+++} + e^{-}$	—0.77
$2Hg = Hg_2^{++} + 2e^{-}$	—0.79
$Ag = Ag^{+} + e^{-}$	—0.80
$Hg_2^{++} = 2Hg^{++} + 2e^{-}$	—0.92
$2Br^{-} = Br_2(l) + 2e^{-}$	—1.07

Half cell Reaction	E° (volts)
$NO + 2H_2O = NO_3^{-} + 4H^{+} + 4e^{-}$	—0.96
$2H_2O = O_2 + 4H^{+} + 4e^{-}$	—1.23
$2\,Cr^{+++} + 7H_2O = Cr_2O_7^{--} + 14H^{+} + 6e^{-}$	—1.33
$2Cl^{-} = Cl_2 + 2e^{-}$	—1.36
$Au = Au^{+++} + 3e^{-}$	—1.50
$Mn^{+2} + 4H_2O = MnO_4^{-} + 8H^{+} + 5e$	—1.51
$2F^{-} = F_2 + 2e^{-}$	—2.87

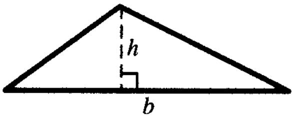
GEOMETRIC FORMULAS

Triangles



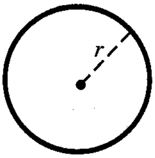
Right Triangle

Pythagorean Theorem	$a^2 + b^2 = c^2$



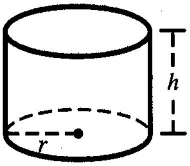
Any Triangle

Area	$A = \frac{1}{2}bh$



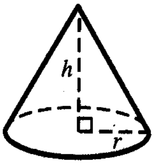
Circles

Area	$A = \pi r^2$
Circumference	$C = 2\pi r$



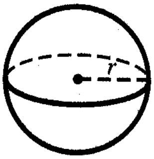
Cylinders

Surface Area	$S = 2\pi r^2 + 2\pi rh$
Volume	$V = \pi r^2 h$



Cones

Surface Area	$S = \pi r^2 + \pi r\sqrt{r^2 + h^2}$
Volume	$V = \frac{1}{3}\pi r^2 h$



Spheres

Surface Area	$S = 4\pi r^2$
Volume	$V = \frac{4}{3}\pi r^3$

GS106 Chemical Bonds and Chemistry of Water

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I. Introduction

A. Hierarchy of chemical substances

1. atoms of elements - smallest particles of matter with unique physical and chemical properties, that still retain the properties of matter

a. e.g. hydrogen, oxygen

2. Isotopes of elements

a. isotopes of a given element are represented by atoms with the same atomic number, but different numbers of neutrons

b. e.g Oxygen Isotopes

(1) ^{18}O - less common variety of oxygen, 8 protons + 10 neutrons

(2) ^{16}O- most common variety of oxygen, 8 protons + 8 neutrons

3. Ion - charged atomic particle

a. atoms that gain or lose electrons, result in net positive or negative charge

(1) the number of protons remains unchanged, but the number of electrons changes to result in net charge

b. cation - positively charged atoms that lose electrons

(1) e.g. H^{+1} hydrogen that has lost 1 electron

c. anion - negatively charged atoms that gain electrons

(1) e.g. $^{16}O^{-2}$ Oxygen 16 ion that has gained 2 electrons, 8 protons

d. Complex cations and anions - ions comprised of more than 1 element, "compound ions"

(1) e.g. HCO_3^- bicarbonate anion

Common Dissolved Ions Found in Natural Waters

Na^+	sodium	Mg^{+2}	magnesium	Ca^{+2}	calcium	K^+	potassium
Sr^{+2}	strontium	Cl^-	chloride	$SO4^{-2}$	sulfate		$HCO3^-$ bicarbonate
Br^-	bromide	Fe^{+2} iron	Fe^{+3} iron				

4. molecules of 1 or more atoms of elements

a. e.g. water molecule (H_2O)

b. e.g. $2\ H^{+1} + O^{-2} = H_20$

5. compounds of elements bonded together

a. physical and chemical properties of compounds differ from that of the constituent atoms of elements

b. e.g. sodium chloride (NaCl)

6. mixtures of unbonded elements and compounds

a. e.g. mixture of salt and sugar

B. Chemical Bonds

1. Atomic Forces that hold atoms together in molecules, or ions in crystals

   a. atoms form bonds with other atoms to form compounds
   b. all physical properties of chemical compounds are controlled by the atomic arrangement and bonding characteristics of the component atoms
   c. bonding between atoms is largely controlled by the electron configuration of the outermost (valence) electron shell

      (1) bond style is controlled by octet rule - tendency for atoms to attain a stable 8-electron configuration in the outermost valence shell
         (a) exception to octet rule = hydrogen - tendency towards 2 electrons in outermost shell

      (2) Note: for the Noble Gases on the far-right column of the periodic chart, the outmost valence shell is full, thus the noble gases are intert (non-reactive)

example of chemical bonding and octet rule: Na^{+1} + Cl^{-1} --------- NaCl

e.g. NaCl - Na has an atomic no. of 11, and thus contains 11 electrons around the nucleus (2 in first energy level, 8 in second energy level, and 1 in valence or outer energy level); Cl has an atomic no. of 17 and thus 17 electrons about its nucleus (2 in first level, 8 in second level, 7 in outer level). Thus Na needs to lose 1 electron from outer shell to obtain stable configuration, and Cl needs to gain 1 electron in outer shell to obtain stable configuration.... tendancy for ionic bonding to form NaCl.

2. Lewis Electron Dot Models of Atoms

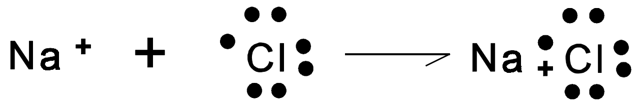
   a. electron dot models represent the configuration of the valence electron shell, or outermost shell

      (1) outershell electrons are filled 1 by 1 around the nucleus, and then paired to form a "square dance" set

In-Class Exercise - Using the periodic chart, write the lewis electron dot models for the following atoms:

K H C Si Ca F O

b. representing chemical reactions with dot models



In-Class Exercise: write the electron dot models for H and Cl, show the dot-model reaction that froms hydrochloric acid (H + Cl ----- HCl)

Write the electron dot model reaction of Mg + O to form MgO

Write the electron dot model reaction for 2 K + O to form K_20

Write a chemical reaction calcium + choride to form calcim chloride

3. Bond Types
    a. ionic bonds - transfer of electrons between atoms
    b. covalent bonds - sharing of electrons between atoms
    c. Metallic bonding - extreme case of electron sharing in which electrons move freely from atom to atom. Metallic bonding accounts fo the high electrical conductivity of metals and other special properties.

C. Aqueous Solutions

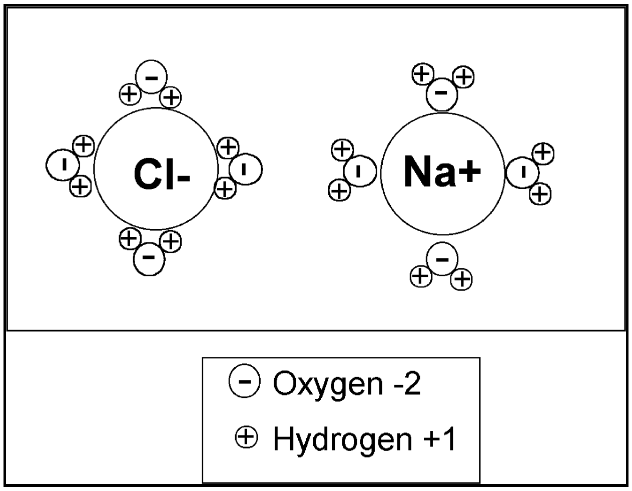
1. water-based solutions - homogeneous mixture of two or more substances
    a. homogeneous - mixing throughout with individual ions separated apart from others

2. solute - the substance being dissolved

3. solvent - the substance doing the dissolving
    a. water is associated with a high degree of dissolving power

4. e.g. saline solution - adding salt to water
    a. water - dipolar molecule with + and - ends to the molecule
    b. a "sheath of hydration surrounds the sodium and chlorine atoms to force them apart electrostatically

$NaCl + H_2O$ --------- $Na^+ + Cl^- + H_2O$



D. Measuring concentrations of solutes in aqueous solutions

1. concentration - measurement of the quantity of solute in a given quantity of solvent (or solution)
    a. Mass Percent = (mass solute / total mass solution) * 100%

E.g. if 5 g of NaCl is dissolved in 95 g of water, what is the mass percent of sodium chloride in the solution?

conversion factors for mass: 1 gram = 1000 mg, 1 kg = 1000 g, 1 gram = 1,000,000 micrograms

(1) percent = "parts per hundred" (%)

b. Parts per Thousand (o/oo) = grams of solute / liter of water

Determine the concentration in ppt for a solution of 200 gram dissolved in 2 liters of water?

Determine the concentration in ppt for a solution of 2000 mg dissolved in 1 liter of water?

c. Parts per Million = milligrams of solute / liter of water

Determine the concentration in ppm for a solution 20 mg of salt per liter of water?

What about 20 kg of salt per liter of water?

d. Parts per Billion = micrograms of solute / liter of water

Determine the concentration in ppb for a solution of 200 micrograms of salt dissolved in 3 liters of water?

Determine the concentration in ppb for a solution 200 grams of salt dissolved in 4 liters of water?

e. Molarity = amount of solute in moles / volume of solution in liters

(1) Mole - the amount of a substance that contains exactly the number of elementary entities as there are in carbon-12 atoms in exactly 12 g of carbon-12

(a) Avagadro's number - a constant, the number of carbon-12 atoms contained in 12 g of carbon

1 mol $^{12}C = 6.022 \times 10^{23}$ ^{12}C atoms = 12.0 gram = the atomic mass of 1 atom of ^{12}C

1 mol $^{16}O = 6.022 \times 10^{23}$ ^{16}O atoms = 15.99 grams = the atomic mass of 1 atom of ^{16}O

1 mol of NaCl = 6.022×10^{23} NaCl molecules = atomic mass of Na + atomic mass of Cl = 23 + 35 = 58 grams = the formula weight of 1 molecule of NaCl

Question: how many atoms are contained in 1 mole of chlorine-35? What is the mass of 1 mole of chlorine 35?

Question: if you had 24 grams of ^{12}C, how many moles would you have?

Question: if you had 48 grams of ^{16}O, how many moles would you have?

Question: What is the molarity of a solution with 75 grams of Cl in 2 liters of water?

Question: If you had 236 grams of NaCl, how many moles would you have?

Question: What is the molarity of a solution with 236 grams of NaCl dissolved in 4.2 liters of water?

f. Molality = amount of solute in moles / mass of solvent (in kilograms)

(1) molality differs from molarity in that it is based on mass of solvent, rather than volume, eliminates temperature variation effects on volume of liquids

Conversion Factor: 1 liter of water = 1 kg mass of water

question: what is the mass of 4.2 liters of water in kg?

question: what is the molality of a solution with 236 grams of NaCl dissolved in 4.2 liters of water?

II. Physical and Chemical Properties of Water

A. Can exist in all three physical states: liquid, solid (ice), and gas (water vapor)
B. Transformation Processes related to energy input and entropy of water: heating of water, > atomic activity of the water molecules, i.e. > vibrational energy of water atoms.

1. ICE ----------HEAT----- WATER-------HEAT -------WATER VAPOR
(<32 degrees) (32-212) (>212 degrees F)

C. Water is one of few earth substances that remains in a liquid state at the operating surface temperatures of the earth.

1. The liquidity of water makes it a dominant and pervasive component of all earth processes

D. Water has High Heat Capacity- it has a capacity to absorb and hold energy with only a small amount of temperature rise.

1. important for water-based organisms to regulate temperature
2. produces the moderating effects of oceans on climate
    a. oceans = warm residual heat in winter (warms air temp.)
    b. oceans = slow rate of heating in summer (cools air temp.)

E. Water expands in volume when it freezes/ becomes colder, in contrast to majority of substances (which contract when colder)

1. Result Density of ice < Density of water: thus ice floats on water
2. The crystal structure of ice is a hexagonal arrangement of water molecules
    a. creates increased volume and decrease in density
3. importance: lakes and oceans freeze from top down, life would not be possible if ice was more dense than water (i.e. freezing from bottom to top).

F. Water strongly influenced by the force of gravity, constantly driven downward, and can possess great erosive/ landscape carving force

G. Water has property of high surface tension, ability to have strong molecular attractive forces (sticks to itself and electrostatically attracts ionic forms of elements)

1. surface tension - dipolar molecules and hydrogen bonds result in surface tension on top of water mass

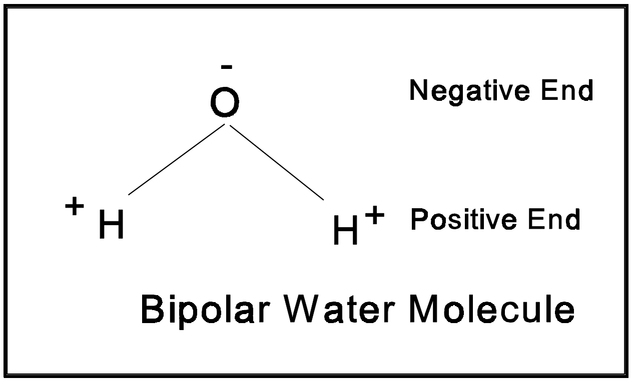
a. surface tension = intermolecular force
b. water surface may support masses of materials

2. Capillarity- phenomena of water moving upward against the force of gravity, due to strong electrostatic adhesive forces, most notable in narrow, restricted pore spaces where surface to surface contact in high.

H. Water acts as a "universal solvent" and can dissolve most any substance over time. Water + carbon dioxide forms a mild carbonic acid solution naturally in hydrosphere, as an acid can result in cationic exchange with positive ionic species, and result in chemical breakdown of substances.

1. Bipolar Water Molecule H_2O

2. Covalent bonds between hydrogen and oxygen (strong bond, via sharing of electrons)
a. Hydrogen: 1 valence electron (atomic no. of 1)
b. Oxygen: 6 valence electrons (atomic no. of 8)



Bipolar Water Molecule

3. Hydrogen bonds- given a mass of water molecules, the opposite ends will attract molecularly, forming weak hydrogen bonds

a. hydrogen bond between molecules is weaker than covalent within molecules
(1) water mass is fluid, but molecules are difficult to dissociate
(2) the weak hydrogen bonds between molecules allow water flow

b. Frozen state - water mass is defined by solid, rigid crystalline structure

   (1) molecular vibrational energy decreases to the point where the hydrogen bonds lock the molecules into a crystalline structure
   (2) hexagonal crystal lattice with increased volume
   (3) freezing point at 32 F (0C) for pure water, but supercooling of water is possible in impurities are present (dissolved salt, suspended solids)

c. Evaporation - molecular vibrational energy increases, breaks hydrogen bonds between molecules, individual molecules are liberated from water mass
   (1) evaporation at air-sea interface is at temp. < boiling point

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Overview of Physical Properties of Water

A. Temperature-Density-Viscosity Relations

Temp. (C)	Density (gm/cm3)	Viscosity (centipoises)
5	0.999965	1.5188
10	0.997000	1.3097
15	0.999099	1.1447
20	0.998203	1.0087
25	0.997044	0.8949
30	0.995646	0.8004
35	0.99403	0.7208
100	0.95865	

Note: viscosity is the measure of a fluid's resistance to flow. The higher the viscosity (e.g. molasses), the more sticky and resistant to flow the fluid is.

B. Weight Density of Water

at 40 F, weight density = 62.4 lb/ft^3 (1 ft^3 = 7.48 gallons)
at 200 F, weight density = 60.135 lb/ft^3

C. Boiling Points of Water vs. Elevation (atmospheric pressure)

Elevation (ft)	Boiling Point (F)
-1000	213.8
0	121
5000	202.9
10,000	193.7

In-Class Exercise

How many pounds will 500 gallons of water weigh? Show all of your math work.

If someone were to give you 3000 pounds of water, how many gallons would you have? How many cubic feet? Show all of your math work.

Primer on Solving Quantitative Style Word Problems in Physical Science and Geology

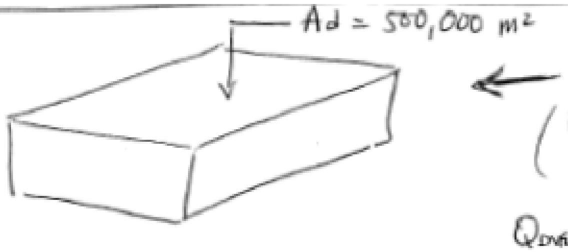
Compile by Dr. Taylor, Jan. 23, 2011

(1) Carefully read the word problem
(2) Identify all the variables
    a. ID Knowns
    b. ID Unknowns
(3) Draw and sketch the problem, labeling all the variables with magnitudes and units
(4) Convert all units to consistent dimensions; use unit algebra techniques, cancel units
(5) List all equations that apply to the problem, refer to class notes and text book
(6) Rearrange equations, substitute variables, algebraically solve for the unknown(s)
(7) Check your work, review your math, review your unit algebra, does the value of your answer make logical sense? For example, if you calculate the volume of the Earth as 6 gallons, something is not right, and you need to go back to the drawing board.

Example Problem 1.2 Assume you are dealing with a vertical-walled reservoir having a surface area of 500,000 m^2 and that an inflow of 1.0 m^3/sec occurs. How many hours will it take to raise the reservoir level by 30 cm?

Stepwise solution to problem 1.2

1.2



INflow =

$$\left(\frac{1\ m^3}{\cancel{sec}}\right)\left(\frac{60\ \cancel{sec}}{\cancel{min}}\right)\left(\frac{60\ \cancel{min}}{hr}\right) =$$

$$Q_{INflow} = 3600\ \frac{m^3}{hr} = \text{INflow RATE}$$

$$Vol = A \cdot d$$

$$d = 30\ \cancel{cm}\ \frac{1\ m}{100\ \cancel{cm}} = 0.3\ m$$

$$Vol = (500{,}000\ m^2)(0.3\ m) = 150{,}000\ m^3$$

$$t\ (Q_{inflow}) = \frac{Vol}{\cancel{t}}\ \cancel{t}$$

$$t\ Q = Vol$$

$$t = \frac{Vol}{Q} = \frac{150{,}000\ m^3}{3600\ m^3/hr} = \boxed{41.7\ hr}$$

UNITS: SI units (Systéme Internationale d'Unités)

Base SI units

length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

examples of derived units

velocity	m/s
acceleration	m/s^2
area	m^2
density	kg/m^3

Dimensional Analysis $\cdots$ Do the units work out ?

In math class we see quadratic equations of the form

$$y = ax^2 + bx + c$$

all the time and never question its validity. In physics, every quantity has units associated with it (the exception being the ratio of two expressions having the same units). Dimensional analysis allows us to check if the mathematical expression we are using in dimensionally correct. In a short while you'll see the following equation:

$$x(t) = \frac{1}{2}at^2 + v_0 t + x_0$$

where $x(t)$ and x_0 are measured in meters (m), t in seconds (s), the initial velocity v_0 in meters/sec (m/s), and acceleration a in m/s^2. By substituting in the appropriate units for each quantity we observe that

$$m = (\frac{m}{s^2}) * (s)^2 + (\frac{m}{s}) * s + m = m + m + m,$$

verifying that the expression is indeed dimensionally correct.

Had we mistakenly put the squared on the second occurrence of time (t) in the equation rather than the first we'd have

$$x(t) = \frac{1}{2}at + v_0t^2 + x_0,$$

which would lead to the following dimensionalities:

$$m = (\frac{m}{s^2}) * (s) + (\frac{m}{s}) * (s)^2 + m = \frac{m}{s} + m * s + m.$$

Note that the addition operation is now ill-defined; you can only add quantities of the same type. Thus, checking equations using dimensional analysis helps to catch algebraic mistakes you might make during mathematical manipulations.

Another equation we'll derive when we begin studying projectile motion is known as the range equation:

$$R = \frac{v_0^2 \sin{(2\theta_0)}}{g},$$

where R is the horizontal distance traveled (the Range), v_0 is the initial velocity, θ_0 is the angle it is launched at relative to the horizontal, and g is the acceleration due to gravity. Inserting the units demonstrates that

$$m = \frac{(\frac{m}{s})^2 * 1}{(\frac{m}{s^2})} = m.$$

Note that in our units check I've inserted "1" for the units of the sine function, trigonometric functions are pure numbers, they have no units associated with them.

Powers of ten

Usually we'll use the power of ten that is most convenient for the problem at hand. For a problem involving the thickness of a cell wall, length measurements will often be in terms of nanometers (1 nm $= 10^{-9}$ m), while for a car traveling down the highway a more appropriate unit of measurement might be the kilometer (1 km $= 10^3$ m). Some commonly used unit prefixes and powers of ten:

pico	p	10^{-12}	tera	T	10^{12}
nano	n	10^{-9}	giga	G	10^{9}
micro	μ	10^{-6}	mega	M	10^{6}
milli	m	10^{-3}	kilo	k	10^{3}
centi	c	10^{-2}			

Unit Conversions $\cdots$ always multiply by one!

Basic idea: since 1 minute = 60 seconds, divide each side by 60 seconds to get:

$$\frac{1\text{ minute}}{60\text{ seconds}} = \frac{60\text{ seconds}}{60\text{ seconds}} = 1$$

We could just have easily divided by 1 minute to arrive at:

$$\frac{60\text{ seconds}}{1\text{ minute}} = \frac{1\text{ minute}}{1\text{ minute}} = 1.$$

Since multiplying by 1 leaves the value of a quantity unchanged, we can accomplish our conversions from one system of units to another by multiplying by the "appropriate form" of 1.

Example: lets convert 55 miles/hour to meters/second.

$$\frac{55\ \mathrm{mi}}{1\ \mathrm{hr}}=\left(\frac{55\ \cancel{\mathrm{mi}}}{1\ \cancel{\mathrm{hr}}}\right)\left(\frac{1\ \cancel{\mathrm{hr}}}{60\ \cancel{\mathrm{min}}}\right)\left(\frac{1\ \cancel{\mathrm{min}}}{60\ \mathrm{sec}}\right)\left(\frac{5280\ \cancel{\mathrm{ft}}}{1\ \cancel{\mathrm{mi}}}\right)\left(\frac{12\ \cancel{\mathrm{in}}}{1\ \cancel{\mathrm{ft}}}\right)\left(\frac{2.54\ \cancel{\mathrm{cm}}}{1\ \cancel{\mathrm{in}}}\right)\left(\frac{1\ \mathrm{m}}{100\ \cancel{\mathrm{cm}}}\right)$$

$$\frac{55\ \mathrm{mi}}{1\ \mathrm{hr}}=\left(\frac{55*5280*12*2.54}{60*60*100}\right)\left(\frac{\mathrm{m}}{\mathrm{s}}\right)$$

$$\text{Thus } \frac{55\ \mathrm{mi}}{1\ \mathrm{hr}}=24.6\frac{\mathrm{m}}{\mathrm{s}}.$$

Another example: convert 2.7 grams/cm^3 to kg/m^3.

$$\frac{2.7\ \mathrm{gr}}{1\ \mathrm{cm}^3}=\left(\frac{2.7\ \cancel{\mathrm{gr}}}{1\ \cancel{\mathrm{cm}^3}}\right)\left(\frac{1\ \mathrm{kg}}{10^3\ \cancel{\mathrm{gr}}}\right)\left(\frac{10^2\ \cancel{\mathrm{cm}}}{1\ \mathrm{m}}\right)^3$$

$$\text{Thus } \frac{2.7\ \mathrm{gr}}{1\ \mathrm{cm}^3}=\left(\frac{2.7*10^6}{10^3}\right)\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right)=2.7*10^3\left(\frac{\mathrm{kg}}{\mathrm{m}^3}\right)$$

GS 106 Notes - Water Pollution

I. Water as a Natural Resource

- A. Near-Surface Components of Hydrologic Cycle
  - 1. Oceans
  - 2. Rivers
  - 3. Groundwater

- B. Water as a Resource (Important Uses)
  - 1. Required for Life: Plants, Animals
  - 2. Human Consumption
  - 3. Irrigation / Agricultural Production
  - 4. Industrial Processing
  - 5. Domestic Wastewater Management (sewage)

- C. Water Use in the United States
  - 1. Basic Budget (approximate)
    - a. U.S. Rainfall = 4200 billion gal/day (input)
    - b. Evapotranspiration = 2750 billion gal/day (output)
    - c. Streamflow+Groundwater = 1400 billion gal/day

  - 2. Human Consumption of Water
    - a. average human needs 1 gal/day for internal consumption
    - b. U.S. daily consumption = 400 billion gallons per day
    - c. Actual Use = 1800 gal/person/day
      - (1) consumption, cooking, washing, industrial, agricultural

  - 3. Water Resource Problems
    - a. Water use does not match population / needs
    - b. water pollution reduces effective amount available for use

  - 4. Water Supplies in U.S.
    - a. Surface Water vs. Groundwater
      - (1) surface water important in humid regions
      - (2) groundwater important in arid regions
        - (a) largest reservoir of unfrozen fresh water
    - b. Seasonal Variation in Water supply
      - (1) droughts
      - (2) seasonal rainfall changes
    - c. Dams and Water Reservoirs
    - d. Highest Water Use
      - (1) Urban Areas
      - (2) SW U.S.
        - (a) irrigation
        - (b) high population growth
        - (c) arid conditions

II. Water Pollution Issues
- A. Introduction
    - 1. water is a good solvent, commonly associated with dissolved chemical constituents
    - 2. "pollution" - contamination of water with unwanted or hazardous chemical constituents
    - 3. common pollution sources
        - a. industry
        - b. agriculture
        - c. domestic sewage

- B. Natural Geochemical Cycles
    - 1. water dissolving elemental constituents from rock and sediment material
    - 2. Commonly dissolved weathering products from rock material
        - a. calcium, iron, sulfer, sodium, chloride, magnesium

- C. Residence Time - duration with which water resides in Earth reservoir systems
    - 1. > residence time > opportunity for dissolution and addition of dissolved chemical constituents
    - 2. residence time of dissolved ions - the lenght of time that individual ionic species are present in a dissolved state before they are removed by natural "attenuation" processes

- D. Pollution Sources
    - 1. Point vs. Nonpoint Sources
        - a. point pollution - pollutants are released at a discrete point of discharge
            - (1) e.g. a sewer outlet
        - b. nonpoint pollution - pollutants are released as diffuse contaminants from across the landscape
            - (1) e.g. fertilizer runoff from farmland
            - (2) petroleum-based runoff from parking lots

    - 2. Industrial Pollution - 10's of thousands of chemicals are created each year by industrial and pharmaceutical chemists, industry forms a primary source of water pollution

        - a. Inorganic Pollutants - Metals
            - (1) e.g. mercury
                - (a) naturally occurring in rocks, thermometers, equipment
                - (b) very toxic, affects nervous system
                - (c) propagates easily through the food chain (e.g. seafood)
            - (2) Other metals - all toxic to system
                - (a) chromium - common in metals manufacturing
                - (b) lead - common in mining, batteries
                - (c) cadium
                - (d) iodine
        - b. Other Inorganic Pollutants
            - (1) industrial acids
            - (2) acid mine drainage

            - (a) common in coal and sulfide mining districts
        - (3) asbestos - carcinogenic

    - c. Organic Pollutants
        - (1) organic chemicals - carbon-based compounds
        - (2) 1000's of naturally occurring and synthetic organic compounds exist
        - (3) some organic chemicals are extremely carcinogenic or toxic to humans and animals
        - (4) examples
            - (a) oil spills
            - (b) leaking gas storage tanks
            - (c) PCB's - polychlorinated biphenyls - common as coolant in electrical equipment

    - d. Thermal Pollution of Water
        - (1) hot water pollution
        - (2) destructive of cold water fisheries and other organisms
        - (3) sources of thermal pollution
            - (a) power plants (cooling water)
            - (b) industrial cooling processes

    - e. Microorganisms
        - (1) sewage discharge - source of viruses and bacteria
        - (2) excess nutrient discharge - nitrogen
            - (a) nitrogen is important fertilizaer source for plants
            - (b) algal blooms, excessive algal growth
        - (3) eutrophication - excessive algal and plant growth with deposition of organic matter to bottom of surface water bodies
            - (a) result: organic infilling of water bodies and oxygen deficient environments

    - f. Agricultural Pollution
        - (1) Fertilizers - nitrogen and phosphorous
            - (a) fertilizer runoff in streams and lakes
            - (b) excessive plant growth / eutrophication
            - (c) nitrate contamination -"blue baby syndrome"
        - (2) Sediment Pollution - erosion and surface runoff
        - (3) Herbicides and Pesticides

- E. Pollution Prevention and Remediation

    - 1. pollution prevention devices
    - 2. ground and surface water remediation
        - a. chemical treatment strategies