Essentials of medical geology: Impacts of the natural environment on public health

Edited by Olle Selinus, Brian Alloway, José A. Centeno, Robert B. Finkelman, Ron Fuge, Ulf Lindh and Pauline Smedley

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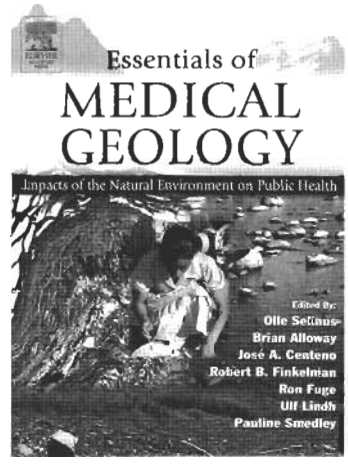

S250 Science in context, Science, Level 2, Topic 3: Water and well-being: arsenic in Bangladesh

by Steve Drury

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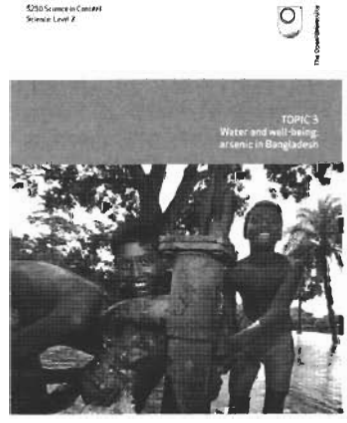

Scalding, baking, suffocating or slow poisoning—Mother Earth has many ways of severely affecting your health. Medical geology is defined as the science dealing with the relationship between natural geological factors and health problems in man and animals. Ever since the catastrophe at Herculaneum and Pompeii in 79 AD, it has been obvious that volcanoes can be bad for human health but, with the passing of time, the more insidious effects of natural poisoning began to be recognised. For example, contemporary writers noted that Roman criminals, used as slaves to mine cinnabar (a mercury ore) at Almaden, Spain, had a life-expectancy of less than three years, by the 16th century, descriptions of mercury poisoning of miners began to appear (Paracelsus, 1567; Scopoli, 1761; Parés y Franqués, 1778). In an account of the numerous diseases to which miners were prone, Agricola (1556, Book VI), included dust-induced "asthma" and a disease afflicting miners in the Carpathian Mountains which caused premature death from a "terrible consumption". Paracelsus (1567) who, like Agricola, worked as a physician in the town of Jácymov (Joachimsthal) in the Erzgebirge (Ore mountains) which separate the present-day Czech Republic from Germany, also reported a high mortality rate from lung diseases amongst miners. Radon (^{222}Rn) gas, originally known as "radium emanation", was discovered by Friedrich Dorn in 1900 and these latter accounts have been assumed by modern writers to refer to the radon-induced lung-cancer now recognised to have occurred amongst miners working the uranium-bearing cobalt and silver mines at Jácymov (Czech Republic) and the near-by Schneeberg (Germany). Appleton's paper in this volume gives an undated observation (p. 239) that "air escaping from an open uranium mine gallery in the town of Schneeberg, Germany, contained up to 10,000 Bq m^{-3} radon". This is of the same order as measurements made in the 1950s which recorded ~5,500 to 7,000 Bq m^{-3} radon in the mine galleries. As a yardstick, remediation measures on a domestic dwelling in the UK would be regarded as essential if the annual average radon concentration level exceeded 200 Bq m^{-3} (p. 258). A causal connection between the miners' lung cancer and the presence of radon was first postulated by Ludewig and Lorenser (1924), but it was a study by Hueper (1942), which showed definitively that both non-occupational factors (e.g. smoking) and occupational factors other than radon could be eliminated from consideration, although complete proof of causation came with quantitative studies of radiation carcinogenesis in the 1950s.

A catalogue of additional adverse health effects in both man and animals as a result of either elemental excess or deficiency in soils, water or air, are encountered in *Essentials of Medical Geology*, a thick and sumptuously produced book, printed in China with 267 illustrations, almost all of which are in colour, and 178 tables. It is a pleasure to read, although with an approximately A4-size page and over 800 pages of coated paper, it is rather heavy.

Its background lies in an initiative of the International Union of Geological Sciences, which established an International Working Group on Medical Geology in 1996 with the aim of increasing awareness of this topic among scientists, the medical world and the general public. In 2000, Medical Geology became Project 454 of the United Nations Educational, Scientific and Cultural Organisation's International Geological Correlation Programme. This led to a number of short courses on Medical Geology being offered around the world and these resulted in the production of this book, first planned in 1998. Its stated aim "as a reference and as a general textbook" is to emphasise "the importance of geology in health and disease in humans and animals". What makes it so interesting is that its authorship ranges from geochemists to pathologists, epidemiologists, analytical chemists and toxicologists, each of whom contribute to different Chapters. The majority (27) of the 59 contributors come from the USA, plus eleven from the UK, five each from Canada and Sweden, two each from Australia, Denmark and Jamaica, and one each from Germany, Italy, Kenya, New Zealand, and Taiwan. Following a Preface by the editors (of whom Olle Selinus of the Geological Survey of Sweden is Editor-in-Chief), Chapter 1, (entitled 'Medical Geology: Perspectives and Prospects'; 13 pp., 80 references) by B. E. Davies, C. Bowman, T. C. Davies and O. Selinus, gives a brief history of the development of the subject and serves as a background to the rest of the volume. Although there are references in their paper to work by members of the former Applied Geochemistry Research Group (AGRG) at Imperial College, London, led by Professor John Webb, I think it is a pity that the groundbreaking *Wolfson Geochemical Atlas of England and Wales* (Webb et al., 1978) did not rate a mention (although it is briefly cited, as authored by an unexplained "AGRG", in Chapter 11). Following from Webb's early interest in geochemistry and agricultural problems (Webb 1964, 1971; Webb et al. 1968), it demonstrated the feasibility of his concept of a regional multi-purpose multi-element geochemical atlas based on relatively high density drainage sediment sampling, and set a standard for geochemical atlases later to be undertaken by geological surveys in many parts of the world. The rest of the book's contents is divided into four sections: 'Environmental Biology', 'Pathways and Exposures', 'Environmental Toxicology, Pathology, and Medical Geology' and 'Techniques and Tools'.

Section 1, introduced by U. Lindh, comprises Chapters 2 to 8 (183 pp., 23% of the text). Chapter 2, 'Natural Distribution and Abundance of Elements' (24 pp., 49 refs.), by R.G. Garrett, introduces mineral chemistry and the biogeochemical cycle, illustrates the natural distribution of elements at regional and continental scales, shows how the distribution of element concentrations can vary in both their central tendancy and range between similar lithologies of different ages (e.g. molybdenum and cadmium in different black shale formations of Cretaceous age), and discusses the establishment and interpretation of geochemical baselines—the natural background (baseline) concentration level of an element in a stated target population covering a distinct geological or geographical entity. Garrett makes the point that both sampling medium and analytical technique need to be taken into account if a reasonable assessment of bioavailability is required. Chapter 3, 'Anthropogenic Sources' (17 pp., 33 refs.), by R. Fuge, summarises the many human activities which have resulted in both localised or more widespread environmental contamination (e.g. long-range aerial deposition at a regional scale from industrial plants or the legacy of world-wide contamination from nuclear weapons testing and the 1986 Chernobyl event): mineral extraction and processing; smelting and refining of metal ores and concentrates; power generation from the burning of fossil fuels, nuclear, geothermal and hydroelectric power; other industrial and manufacturing activities; waste disposal from domestic and industrial sources; agricultural practices; transportation; and the treatment and transport of water. This is a most interesting survey and there are certainly some sources in this section which one might not immediately think of, such as contamination by fluorine from brick manufacture and arsenic in spent waters from geothermal power production. Chapter 4, 'Uptake of Elements from a Chemical Point of View' (24 pp., 14 refs.), by R. J. P. Williams, explains the basic chemistry of the cell and how the chemical composition of the primitive sea influenced the chemical reactions and elements essential for life. Chapter 5, 'Uptake of Elements from a Biological Point of View' (27 pp., 81 refs), by U. Lindh, discusses the nature of the essential elements and the mechanisms for their uptake, and how those elements not essential, or even detrimental to an organism, are excluded. Particular emphasis is placed on the roles of iron, zinc and copper. Chapter 6, 'Biological Functions of the Elements' (45 pp., 141 refs.) by U. Lindh, enlarges on the fact that for each element there is an optimum concentration range: if its concentration falls below some minimum value, health effects arising from deficiency occur, too much and toxicity will result (e.g. iron-induced anaemia on the one hand, and the fact that accidental ingestion of iron tablets is a frequent cause of fatal poisoning in children younger than six years old). The roles of major, minor and trace elements are examined in detail. Chapter 7, 'Geological Impacts on Nutrition' (16 pp., 30 refs), by G. F. Combs jr., again reviews those elements (calcium, chromium, copper, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, selenium, sodium, zinc, and the chloride and fluoride ions) essential for good health and outlines their dietary sources, mineral bioavailability, how their concentrations are determined for clinical assessment in man, and recommended values for dietary intake and optimum concentration ranges in human serum and plasma, etc. Chapter 8, 'Biological Responses of Elements' (21 pp., 30 refs), by M. Nordberg and M. G. Cherian, fills in the picture of element toxicity and deficiency in man in more detail. Specific metals reviewed are: aluminium, cobalt, copper, iodine, iron, manganese, molybdenum, selenium, thallium and zinc; the neurotoxins mercury and lead; and carcinogens arsenic, cadmium and chromium.

Section 2, 'Pathways and Exposures', introduced by R. Fuge, comprises Chapters 9 to 20 (323 pp., 41%). Chapter 9, 'Volcanic Emissions and Health' (23 pp., 61 refs.), by P. Weinstein and A. Cook, is where one discovers that the dangers of volcanic eruption come from more than the lethal effects of volcanic "bombs", molten lava and pyroclastic flows. Not only does fallout of silica- and zeolite-bearing tephra ("volcanic ash") cause severe irritation to eyes, nose, throat, lungs and exposed skin but it may well lead to later lung disease, such as silicosis. Toxic and asphyxiant gases (carbon dioxide, carbon monoxide, hydrogen sulphide, mercury vapour, radon, sulphur dioxide and sulphur trioxide), aerosols (carrying hydrochloric, hydrofluoric and sulphuric acids), fumes and smoke may also be emitted during an eruption. As well as causing direct effects to man and animals in the vicinity, secondary effects will occur via toxic compounds (including those of arsenic, cadmium, copper, lead, mercury, selenium, zinc and fluoride compounds), entering waters, soils and hence the food chain. The authors produce a comprehensive account of all these hazards, and strategies for monitoring them. Chapter 10, 'Radon in Air and Water' (35 pp., 61 refs.), by J. D. Appleton, notes that, as described in my introduction, by the 1950s, a conclusive link between the presence of high concentrations of this naturally occurring radioactive gas and the occurrence of lung cancer in miners working in uranium mines (particularly in Europe and Colorado, USA), had been made. It then began to be recognised that the gas had a deleterious effect on human health at much lower concentrations than occurred in mines and, as a result of migration of the gas from rocks (particularly uraniferous metamorphic rocks, granites and marine black shales) into waters and soils, it could concentrate in houses. The author gives a comprehensive account of these factors, how the risk of radon exceeding a statutory threshold in dwellings sited in a given region is assessed, and what remedial action may be taken. Chapter 11, 'Arsenic in Groundwater and the Environment' (36 pp., 119 refs.) by P. Smedley and D. G. Kinniburgh, begins by reviewing the presence of this toxic element in minerals, rocks, sediments and soils. Although in some parts of the world there are serious local problems caused by contamination from mining, ore-processing and other industrial activity, it is its presence in ground waters in many parts of the world which affects, or potentially threatens, the health of millions of people. The attention of geologists was probably first drawn to the severe threat posed by long-term exposure to arsenic, known in the medical community since at least the 19th century, by a paper (not cited by these authors) presented by Crounse et al. at a symposium "Applied Environmental Geochemistry" held by the AGRG, London, in 1983. Crounse et al. stated that it had long been known in the medical community that long-term exposure to arsenic leads to "dose-related development of keratoic lesions [horny growths] of palms and soles followed, after a latent period of many years, by cancer of the skin" and that "the same association of cutaneous keratoses and cancer plus severe peripheral vascular disease has been demonstrated" in the 1960s in populations with chronic exposure to arsenic in ground water in Taiwan and linked to the incidence of lung cancer in males in Córdoba, central Argentina (see Crounse et al. 1983 and references therein). Since that time arsenicosis has also been recognised as a result of chronic exposure of populations to arsenic-bearing ground waters in the alluvial plains and deltas of Bangladesh and West Bengal (India) which adjoins Bangladesh, Nepal, northern China, Vietnam, Hungary and Romania; and in inland basins in arid and semi-arid areas of Mexico, Chile and the USA (particularly California, Navada and Oklahoma). Smedley and Kinniburgh pay particular attention to Bangladesh (where at least 14,000 people are known to be suffering from arsenicosis from drinking arsenic-contaminated well water and at least 20 million people may be at risk, with a further 40 million in the adjacent Bengal basin) and to the possible causative mechanisms for the problem, as well as discussing possible remediation techniques. Unfortunately, the conclusion of this otherwise useful review that "the detailed mechanisms leading to the release of arsenic to groundwater are still poorly understood" (p. 294) is erroneous, based as it is on a review of the literature which inexcusably omits important papers by Nickson et al. (1998, 2000; 209 and 115 citations respectively, Google Scholar, July 2006) and McArthur et al. (2001, 2004; 85 and 17 citations respectively) from the 119 works in the authors' bibliography. These omitted works suggest that the arsenic in the groundwater derives from reductive dissolution of iron oxyhydroxide (present, for example, as coatings on

sedimentary grains) and release of its sorbed arsenic (which is probably attributable to Late Pleistocene to Recent weathering of arsenic-rich base-metal sulphides upstream in the catchment area) to solution. Microbially-induced reduction of the iron is driven by the presence of natural organic matter in peaty strata both within the aquifer sands and in the overlying confining unit, rather than by the presence of faecally-derived organic matter. They have also demonstrated that (i) arsenic release by oxidation of pyrite and (ii) competitive exchange with fertiliser phosphate both make a negligible contribution to arsenic pollution. (The case of Bangladesh is the subject of the second book reviewed here). Chapter 12, 'Fluoride in Natural Waters' (28 pp., 86 refs.), by M. Edmunds and P. Smedley, points out that while problems with human dental caries as a result of insufficient fluoride intake, requiring supplementation via toothpastes, mouthwashes and even drinking water supplies (e.g. in parts of the UK and USA) are relatively well known, problems with dental and skeletal fluorosis (the latter, at its worst, leading to deformity) in man and animals can occur as a result of anthropogenic activity, such as brick-making (mentioned above) but excess fluoride concentrations naturally occur in ground waters in the western USA, northern Mexico, Argentina, North and East Africa, India and China affecting some 200 million people. These are mainly associated with areas of granitic basement rocks, volcanic areas and geothermal sources, and some sedimentary basins containing debris derived from granitic basements, layers of volcanic ash or phosphatic horizons, etc. Case histories include examples from India, Northern Ghana, the United Kingdom, Sri Lanka, East Africa and Canada. Remediation methods are also discussed. Chapter 13, 'Water Hardness and Health Effects' (14 pp., 64 refs.), by E. Rubenowitz-Lundin and K. M. Hiscock, concerns "hard" water, recognisable by difficulty in getting soap to form a good lather and the presence of "fur" in kettles, which is commonly encountered in water supplies drawn from carbonate rocks and reflects the increase in total calcium and magnesium ions in the water. Drinking hard water has in the past been linked with a general reduction in cardiovascular disease, but more recent studies suggest that it is the increased magnesium level which is linked to reduction in death from acute myocardial infarction ("heart attack"). Although a number of other studies have suggested links with some cancers and eczema, the large number of investigations it has taken over the last 50 years before clarity has emerged in the link to heart disease (largely because of the enormous number of possible confounding variables which have to be considered) suggests that a degree of caution is required in accepting findings reported in these cases without many more corroborative results drawn from other parts of the world. Chapter 14, 'Bioavailability of Elements in Soil' (25 pp., 48 refs.), by B. J. Alloway, reviews the types and properties of soils, their chemistry and the uptake of trace elements by plants—an essential step in the route between parent rock and ingestion of elements by man and livestock. Lead and cadmium are considered in some detail. Chapter 15, 'Selenium Deficiency and Toxicity in the Environment' (42 pp., 82 refs.), by F. Fordyce, notes that this element is an essential component in an enzyme which prevents oxidative cell degeneration. Selenium deficiency has been linked to white muscle disease in animals and is implicated in heart disorder (Keshan disease), bone and joint condition (Kasin-Beck disease) and thyroid-related growth disorders in humans. Selenium toxicosis, characterised by hair and hoof loss in cattle, is also recorded from many parts of the world. Excess selenium generally occurs in association with coal, black shales and phosphatic rocks. Case histories from the USA, Italy, China and Australia are discussed. Chapter 16, 'Soils and Iodine Deficiency' (16 pp., 60 refs.), by R. Fuge, notes that iodine deficiency has long been associated with the occurrence of endemic goiter (in which the thyroid gland becomes enlarged in an attempt to become more efficient), but in infancy (<2 years age) it can lead to cretinism. Although iodine itself was not found until 1811, the use of seaweed in the diet to counteract goitre may date back to 2700 BC. Iodine deficiency disorders are known from many parts of the world, particularly South America, Africa and Asia, but even in the British Isles, goitre was endemic in parts of Wales, Central and South-west England and parts of Ireland, particularly in areas underlain by limestones, as a result of lack of bioavailability in soils. Chapter 17, 'Geophagy and the Involuntary Ingestion of Soil' (23 pp., 99 refs.), by P. W. Abrahams, begins with the observation that geophagy, the deliberate ingestion of soil, is common among both birds (there is a delightful illustration of a macaw eating a lump of soil held in its claw, reminiscent of a human eating a cake!) and animals (one might think of grazing cattle and sheep, but the practice ranges from rabbits to elephants). Among the human population, involuntary ingestion by young children may not be so surprising, but the author documents a fascinating range of deliberate practice from around the world, dating back to prehistoric times but still practiced among communities in West Africa, Bengal, Central America, Turkey, etc. as a "medicament, food detoxifier, psychological comforter, and a supplier of mineral nutrients". However, the practice can lead to toxicity from elements such as potassium and, in contaminated environments, heavy metals. Infection from ingestion of the eggs or larvae of parasitic worms may also occur. Chapter 18, 'Natural Aerosolic Mineral Dusts and Human Health' (21 pp., 14 refs.), by E. Derbyshire, describes how duststorms often arise from wind erosion of desert or other arid regions. They carry with them not only aerosol-sized mineral particles and, it has been suggested (Griffin et al., 2002), may also be a route for bacteria, virus and fungus transmission. Saharan dustfalls in western Europe (often noticeable on car windscreens after rain) are increasing, as are dust storms in other parts of the world. The occurrence of silicosis, pulmonary tuberculosis and non-occupational asbestosis as a result of breathing in aerosol dusts is discussed. Chapter 19, 'The Ecology of Soil-borne Human Pathogens' (30 pp., 40 refs.), by M. W. Bultman, F. S. Fisher and D. Pappagianis, relates to Chapter 17, which mentioned the risk of parasitic diseases as a result of geophagy. Here, the full gamut of unpleasant possibilities arising from life forms naturally present in soils is reviewed: helminths (worms and flukes), protozoa (giving rise to diarrheal disease and other infections), fungi (coccidioidomycosis, histoplasmosis, etc.) , bacteria (anthrax, tetanus, gas gangrene, botulism, Rocky Mountain spotted fever. etc.) and viruses (diarrheal disease, polio, Lassa and hemorrhagic fevers, etc.). The link to geology comes with the formation of clay minerals during weathering of the parent rock. The type and abundance of these governs the soil water potential, soil aggregation and pore size and hence the movement and types of pathogens present in the soil. Chapter 20, 'Animals and Medical Geology' (13 pp., 24 refs.), by B. Jones, introduces the subject and discusses the differences between species and breeds with an emphasis on domesticated animals, particularly cattle, sheep and swine. Specific elements reviewed are aluminium, arsenic, calcium, cobalt, copper, fluorine, iodine, manganese, molybdenum, phosphorus, selenium and zinc.

Section 3, '*Environmental Toxicology, Pathology, and Medical Geology*', introduced by J. A. Centeno, comprises Chapters 21–25 (101 pp., 13%). Chapter 21, '*Environmental Epidemiology*' (11 pp., 6 refs.) by J. B. Nielsen and T.K. Jensen, reviews the study of associations between environmental exposures and the occurrence of disease within a human or animal population. This linkage should be solidly founded on statistical evidence rather than simply an inferential conclusion, and there are too many studies in the geological/geochemical literature which have taken the latter route, probably because many researchers with a geological background do not have an adequate grounding in statistics. The paper explains the differences between ecological, cross-sectional, case-control and cohort studies, the advantages and limitations of each, and the problems caused by confounding, i. e. the mixing of effects, where there can be an exposure to something other than the cause investigated which is associated with the outcome, but which may be unequally distributed among the groups compared. In the example of radon-induced lung cancer, mentioned in my introduction and in Chapter 10, in order to provide conclusive proof of cause, much careful work was necessary to eliminate the

effects of smoking and other possible causative mechanisms. The authors give a cautionary note against the unthinking use of a 95% significance level (commonly used in geological work) for epidemiological hypothesis testing, suggesting that in this case a 99.9% level is more appropriate. This paper should be essential reading for all supervisors of environmental geology/geochemistry projects which include an element of epidemiology, as an object lesson in how such investigations should be carried out, and also by supervisors and examiners of research students and by journal referees for the "Checklist for evaluating an epidemiological paper", which the authors thoughtfully provide. Chapter 22, 'Environmental Medicine' (21 pp., 48 refs.), by J. Fowles, P. Weinstein and C.-H. Tseng, is the study of how the environment affects health. Mechanisms of exposure, dose-response relationships, methods for determining critical thresholds of toxicological effects, and health protection are among the aspects reviewed. Of particular interest in relation to Chapter 11 is that exposure to arsenic in drinking water in Taiwan forms the principal case study. Chapter 23, 'Environmental Pathology' (31 pp., 215 refs.), by J.A. Centeno, F.G. Mullick, K.G. Ishak, T.J. Franks, A.P. Burke, M.N. Koss, D.P. Perl, P.B. Tchounwou and J. P. Pestaner, describes the effects of exposure to toxic trace metals by means of absorption through the skin, ingestion and inhalation. Examples discussed include: arsenic-induced cancer of the skin; the effects of lead, mercury, manganese and tin on the brain; diseases related to inhalation of asbestos; the effects of selenium deficiency and cobalt, copper, iron, lead, magnesium and mercury toxicity on the cardiovascular system and copper and iron toxicity on the liver. Chapter 24, '*Toxicology*' (13 pp.; astonishingly, no other works are cited), by T.L. Guidotti, compliments the previous Chapter by explaining why toxic injury occurs. Chapter 25, 'Speciation of Trace Elements' (21 pp., 61 refs.), by B. Michalke and S. Caroli, reviews the many analytical methods used to determine the quantities in which a chemical species may be present in the human body and the methods by which analysis (requiring accurate determinations at low concentration levels) is achieved. This is important as different species may have quite different properties: e.g., chromium (III) is essential, whereas chromium (VI) is highly toxic. This Chapter might have been better placed following Chapter 29 in the next section.

Section 4, '*Techniques and Tools*', introduced by R.B. Finkelman, comprises Chapters 26 to 31 (132 pp., 17%). Chapter 26, '*GIS [Geographical Information Systems] in Human Health Studies*' (11 pp., 43 refs.), by J.E. Bunnell, A. W. Karlsen, R.B. Finkelman and T. M. Shields, reviews the many sources of information which may be used in conjunction with epidemiological data to assist with problem solving. Case studies include the occurrence of tick-born Lyme disease in the USA and fluorosis in China. Chapter 27, 'Investigating Vector-borne and Zoonotic Diseases with Remote Sensing and GIS' (20 pp., 38 refs.), by S. G. Guptill and C. G. Moore, is concerned with the occurrence of diseases which have a natural reservoir in an animal or non-human species and which can be transferred to humans by an invertebrate (usually an insect, tick or snail). Remote sensing can provide a way of integrating regional information on, say, diurnal temperature, land cover and topography, vegetation moistness and abundance, etc. with mapped disease incidence as a means to obtaining predictive models for disease occurrence. Chapter 28, 'Mineralogy of Bone' (26 pp., 74 refs.), by H. C. W. Skinner, describes the chemistry and mineralogy of bone, methods for its examination, and bone diseases, with particular emphasis on osteoporosis (loss of bone tissue). Chapter 29, 'Inorganic and Organic Geochemistry Techniques' (28 pp., 29 refs.), by M. Vutchkov, G. Lalor and S. Macko, is a very useful survey of the many analytical methods available to assist investigators and compliments those discussed in Chapter 25. Chapter 30, 'Histochemical and Microprobe Analysis in Medical Geology' (11 pp., 20 refs.) by J. A. Centeno, T. Todorov, J.P. Pestaner, F.G. Mullick and W.B. Jonas, discusses the various techniques which are used to determine the nature of particulate materials (e.g. dust or asbestos fibres) present in body tissue (e.g. in the gastric system or the lung) or bone. Chapter 31, 'Modelling Ground water Flow and Quality' (28 pp., 59 refs.) by L.F. Konikow and P.D. Glynn, is a brief review of the computational methods used to achieve quantitative models, obviously of prime importance in the prediction of spread of a contaminant from its source, and subsequent design of remedial methods. Geochemical modelling and sources of code are also discussed.

Finally, there follow three Appendices: A, '*International Reference Values*' (2 pp., 12 refs.), by P. Bobrowsky, R. Paulen, B.J. Alloway and P. Smedley, a compilation of guideline and regulatory maximum values (mg L-1) in drinking water for aluminium, ammonium, antimony, arsenic, boron, barium, beryllium, cadmium, chromium, copper, fluoride, iodine, iron, lead, manganese, mercury, molybdenum, nickel, nitrite, nitrate, selenium, silver, thallium, uranium, vanadium and zinc, (based on information from Australia, Canada, Japan, the European Commission, the United States Environmental Protection Agency and the World Health Organisation published between 1993 and 2004); B, 'Web Links' (2 pp., 34 refs.), annotated URLs for useful sites in relation to Chapters 19 and 26; and C, 'Glossary' which every reader should find helpful for explanation of specialist terms outside their own field of expertise among its 512 terms. The final item is a pretty comprehensive Index (19 pp.) although, rather tiresomely, it does not necessarily enable one to find where papers by a given author are cited in the text. At the end of each Chapter there is a reference to others containing related material.

Overall, *Essentials of Medical Geology* is an extremely impressive volume and should be essential reading for students and professionals involved in environmental geoscience.

However, those wishing to read more about the problems posed to humans by the presence of arsenic in groundwater will find plenty to interest them in *Water and well-being: arsenic in Bangladesh,* a superb little book produced by Steve Drury as part of the Open University (Milton Keynes, UK) Course 250, "Science in context". It begins with a quotation, attributed to an anonymous (?Latin) source that "in any civilised society, the first provision after a system of laws is a safe and reliable water supply". Unfortunately, as documented here, the reader learns how an endeavour to help the people of Bangladesh through an international aid programme to provide improved drinking water supplies (in order to avoid the prevalence of water-borne diseases from surface supplies by provision of water from wells), went tragically wrong. Chapter 1, 'Introduction: two tragedies' (4 pp.), sets the scene with a 19th century poisoning and the "poisoning on an unprecedented scale" now unfolding in Bangladesh. Chapter 2, 'Chemical elements and health' (25 pp.), reviews concepts such as the dose-response curve, the results of element deficiency and toxicity, why particular elements are poisonous, the biochemistry of arsenic and the medical results of arsenicosis (illustrated by epidemiological results from studies in West Bengal, which adjoins Bangladesh, and Taiwan). Chapter 3, 'Geological processes and groundwater' (34 pp.), explains the geological setting in Bangladesh, with particular reference to groundwater, the water chemistry, the geography of the arsenic contamination and theories accounting for the occurrence of the arsenic in the groundwaters. The hypothesis of reductive dissolution of iron (III) hydroxide by anaerobic, methanogenic bacteria assocated with peat-rich layers in the sediment, releasing adsorbed arsenic, is favoured here. The implications for other deltaic regions around the world are discussed. What makes this book of particular interest is that Chapter 4 concerns 'Ethical and legal issues'. It would appear that while the effects of arsenic poisoning were first recognised in West Bengal by D. P. Chakraborty in the early 1980s, his warnings were dismissed as "panic mongering" and ignored by both the Bangladesh Government and the scientific community. The first account, by A. K. Chakraborty and K. C. Saha, appeared in the literature in 1987. The Bangladesh Government's programme of tubewell drilling to provide improved drinking water supplies, had begun in 1972, and by 1992 thousands of both shallow and deep wells had been sunk. It was only in February 1992, that water from

some 150 shallow and deep wells of the 4000 drilled under a project funded by the Overseas Development Agency of the UK Government was sampled, somewhat as an afterthought, and analysed by the British Geological Survey (BGS), partly to see if there might be high concentrations of aluminium, iron, manganese, zinc and phosphate, which might be toxic to fish which rural Bangladeshis were being encouraged to farm. It appears that although the subsequent report contained information on some 31 analytes (including cadmium, chromium and lead) and noted the presence of methane seepages (indicative of the presence of peat at depth) from some wells, no one had thought to analyse for arsenic. (Ironic, in view of the fact that at the 1983 London symposium on "Applied Environmental Geochemistry", mentioned above, specific attention had been drawn to the severe effects of arsenic poisoning in humans from well waters in Taiwan and that a copy of the book of the proceedings, in which the Crounse et al. article appears, is in the BGS library.) Drury notes that although the 1992 BGS report on the results of the chemical analyses did not comment explicitly on the whether the waters were potable or not, a subsequent 1995 BGS report based upon it stated that "the groundwater of the study area was 'suitable for crop irrigation and domestic usage'". It was not until a subsequent geochemical survey of the waters of some 3500 randomly sampled tubewells (an estimated 11 million are now present in Bangladesh) carried out by Mott MacDonald International, the Bangladesh Department of Public health Engineering and the BGS in the late 1990s that it was realised that about half of wells <50 m deep contain from 50 $\mu g\ L^{-1}$ to over 200 $\mu g\ L^{-1}$ of arsenic (the World Health Organisation maximum recommended concentration is 10 $\mu g\ L^{-1}$) and the magnitude of the impending arsenicosis problem began to be recognised, in which millions of people may now be at risk. This Chapter focuses on the legal arguments which have ensued since a group of affected villagers tried to sue the BGS, via its parent organisation, the Natural Environment Research Council (NERC) in 2002 for damages for their ill-health contracted from drinking arsenic-contaminated groundwater which they held had been claimed to be safe in the reporting of the original geochemical survey. The case was declared fit to go to trial by jury in 2003, but in a subsequent appeal by NERC (2004) the case was dismissed. The full judgements for these two hearings are summarized in the rest of this Chapter, and make fascinating reading. Finally, Chapter 5, 'Managing and mitigating the problem' (7 pp.), discusses mitigation methods. The book is completed by a summary of learning outcomes, answers to questions, comments on activities, and an 8 page index. Aimed at a broad readership who are not necessarily geoscientists, the text is very clearly written and well illustrated with 32 figures in colour, plus 6 tables, and contains a number of thought-provoking exercises for the interested reader.

This book should be widely read as a cautionary tale, and also used as a case-study on any undergraduate or postgraduate course concerned with environmental or medical geology or geochemistry. It was published before the results of a further appeal to the Lords of Appeal in the House of Lords by the appellant against the 2004 decision were known; the case was dismissed on 5 July 2006, essentially on the grounds that BGS had no "duty of care" to test for arsenic in their original survey, and that the absence of such analysis carried no implications for the potability of the water supply or otherwise; see Lords of Appeal (2006) for discussion. Nevertheless, it is to be hoped that no future hydrogeochemical survey, in which assessment of the potability of water supply (and hence future risk to human or animal health) is a goal, will omit to include arsenic and the range of other elements potentially toxic to man or animals, within its remit.

References

Agricola, G., 1556, De Re Metallica Libri XII. Froben, Basel. 86 + 538 pp. [English translation, Hoover, H.C., and Hoover, L.H., 1912, The Mining Magazine, London; reprinted, Dover, New York, 1950].

Chakraborty, A. K., and Saha, K. C., 1987, Arsenical dermatosis from tubewell water in West Bengal. Indian Journal of Medical Research, v. 85, pp. 326-334.

Crounse, R. G., Pories, W. J., Bray, J. T., and Mauger, R. L., 1983, Geochemistry and Man: Health and Disease 2. Elements Possibly Essential, Those Toxic and Others, in Thornton, I., (ed.), Applied Environmental Geochemistry. Academic Press, London and New York, pp. 309-333.

Griffin, D. W., Kellog, C. A., Garrison, V. H., and Shinn, E. A., 2002, The Global Transport of Dust: An atmospheric river of dust, microorganisms and toxic chemicals crosses oceans. American Scientist, v. 90, pp. 228-235.

Hueper, W. C., 1942, Occupational Tumors and Allied Diseases. C. C. Thomas, Springfield, Illinois.

Lords of Appeal, 2006, Opinions of the Lords of Appeal for Judgement in the cause Sutradhar (FC) (Appellant) v. Natural Environment Research Council (Respondents). http://www.publications.parliament.uk/pa/ld200506/ldjudgmt/jd60705/sutrad.pdf.

Ludewig, P., and Lorenser, E., 1924, Untersuchungen der Grubenluft in den Schneeberger Gruben auf den Gehalt an Radiumemanation. Zeitschrift für Physik, v. 22, pp. 178-185.

McArthur, J. M., Ravenscroft, P., Safiullah, S., and Thirlwall, M. F., 2001, Arsenic in groundwater: testing pollution mechanisms for sedimentary aquifers in Bangladesh. Water Resources Research, v. 37, pp. 109-117.

McArthur, J. M., Banerjee, D. M., Hudson-Edwards, K. A., Mishra, R., Purohit, R., Ravenscroft, P., Cronin, A., Howarth, R. J., Chatterjee, A., Talukder, T., Lowry, D., Houghton, S., and Chadha, D. K., 2004, Natural organic matter in sedimentary basins and its relation to arsenic in anoxic ground water: the example of West Bengal and its worldwide implications. Applied Geochemistry, v. 19, pp. 1255-1293.

Nickson, R., McArthur, J., Burgess, W., Ahmed, K. M., Ravenscroft, P., and Rahman, M., 1998, Arsenic poisoning of Bangladesh groundwater. Nature, v. 395, p. 338.

Nickson, R. T., McArthur, J. M., Ravenscroft, P., Burgess, W. G., and Ahmed, K. M., 2000, Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. Applied Geochemistry, v. t5, pp. 403-413.

Paracelsus, T., 1567. Von der Bergsucht oder Bergkrankenheiten drey Bücher, inn dreyzehen Tractat verfast unnd beschriben worden. Darinnen begryffen vom ursprung und herkommen derselbigen kranckheiten, sampt ihren warhafftigen Preservativa unnd Curen. S. Mayer, Dillingen, 62 pp. [English translation, Rosen, G., 1941; reprinted 1996 as: Four Treatises of Theophrastus von Hohenheim called Paracelsus. Translated from the original German with introductory essays by C. Lilian Temkin, George Rosen, George Zilboorg and Henry E. Siderist; edited, with a preface, by Henry E. Siderist. Institute of History of Medicine, Johns Hopkins University Press, Baltimore, Maryland, 43-126].

Parés y Franqués, J. 1778. Catástrofe morboso de las Minas Mercuriales de la Villa de Almadén del Azogue. Historia de lo perjudicial de dichas reales Minas a la Salud de sus Operarios: y exposición de la Enfermedades corporales, y médico-Morales de sus Fossores, con la Curación respectiva de ellas. Almadén. MSS. [annotated reprint: Navarro, A.M., (ed.), 1998, Catástrofe Morboso De Las Minas Mercuriales De La Villa De Almadén Del Azogue. Colección Monografías 21, Universidad de Castilla-La Mancha, Cuenca, 397 pp.]

Scopoli, G. A. 1761. Joannis Antonii Scopoli De hydrargyro Idriensi tentamina physico-chymico-medica. I. De minera hydrargyri. II. De vitriolo Idriensi. III. De morbis fossorum hydrargyri. Radiciana, Venice. 94 pp.

Webb, J. S., 1964, Geochemistry and life. New Scientist, v. 23, pp. 504-507.

Webb, J. S., 1971, Regional Geochemical Reconnaissance in Medical Geography in Cannon, H. L., and Hopps, H. C. (eds.), Environmental Geochemistry in Health and Disease. Geological Society of America Memoir 123, Boulder, Colorado, pp. 31-42.

Webb, J. S., Nichol, I., and Thornton, I., 1968, The Broadening Scope of Regional Geochemical Reconnaissance. Proceedings, 22nd International Geological Congress, New Delhi, India, v. 6, pp. 131-147.

Webb, J. S., Thornton, I., Howarth, R. J., Thompson, M., and Lowenstein, P. L., 1978, The Wolfson Geochemical Atlas of England and Wales. Oxford University Press, Oxford.

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