PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Geochemistry and Health in the United Kingdom

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Geochemistry and health in the United Kingdom

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[Plates 1 and 2]

Before the 1960s, comparisons between the distribution of trace elements in the environment and health in the United Kingdom were primarily confined to *ad hoc* studies in areas associated with particular agricultural disorders or with unusual human mortality or morbidity records. More recently, increasing interest in the importance of trace elements in crop and animal production and in the hazards of environmental pollution have created a need for more systematic geochemical data. Geochemical reconnaissance maps for England, Wales, Northern Ireland and parts of Scotland have demonstrated the extent of many known clinical trace element problems in agriculture and have also been valuable in delineating areas within which subclinical disorders may occur. Their application to studies on the composition of soils, food crops and surface waters in relation to public health has proved encouraging. Current knowledge and present investigations into environmental geochemistry and human health in the U.K. are reviewed, together with future research requirements.

The research area of geochemistry and health is concerned primarily with the recognition and understanding of relations between the composition of rocks, soils, air-borne materials, ground and surface waters and the health of plants, livestock and man. In this paper, attention is confined mainly to the trace elements, which may occur naturally in the environment or may be present as contaminants from metalliferous mining and smelting, industry and other activities of man. These metal pollutants interact with the natural components of the environment and must be included in an assessment of the effects of geochemistry on health.

Fifteen or more elements present in rocks and soils in very small amounts are essential for plant and animal nutrition. In the United Kingdom deficiencies of Cu, Co, I, Fe, Mn and Se have been reported in grazing livestock, and of B, Cu, Fe, Mn, Mo and Zn in crops. Excessive amounts of several trace elements may be toxic to plants and/or animals or may affect the quality of food-stuffs and water for human consumption; these include As, B, Cd, Cu, F, Pb, Hg, Mo, Ni, Se and Zn.

Problems affecting the health and production of agricultural crops and livestock due to trace element deficiency or excess are frequently reported in particular areas or regions of the United Kingdom associated with specific geological formations or transported material derived therefrom. Acid igneous and coarse arenaceous sedimentary rocks generally contain smaller amounts of the nutritionally essential trace elements than basic igneous and fine-grained sedimentary rocks. Regional variations in the prevalence of human disease are also recognized (Howe 1970) though relations with the distribution of trace elements are in most cases empirical and in general are less well founded than those with agricultural disorders.

REGIONAL DISTRIBUTION OF TRACE ELEMENTS IN THE ENVIRONMENT

An obvious prerequisite for studies on relations between geochemical parameters and health, is knowledge of the regional distribution of the chemical elements. Concentrations of trace elements in British soils and their parent materials have been reported by Swaine (1955), Mitchell (1971) and many other authors and provide a useful guide to those geological formations and soil types on which problems of deficiency and toxicity in crops and livestock may occur. Ideally, trace element maps for application to agriculture would be based on the systematic sampling and analysis of soil and/or vegetation, but in Britain and Ireland such an approach has to date proved impracticable because of the cost and time necessary to take the numerous closely spaced samples required to take into account variations related to the complex geology and soil types. Information is available for parts of Scotland, but in England, Wales and Northern Ireland there are few systematic data on either total or 'available' levels of trace elements in soils. The Soil Survey of England and Wales have recently published trace element data for typical soil profiles in specific localities (Johnson 1971; Green & Fordham 1973; Robson *et al.* 1974). Trace element maps based on grid sampling in southwest Wales show regional patterns of trace element distribution reflecting variations in parent material and soil type (Rudeforth 1977; Wilkins 1978). Numerous *ad hoc* studies have also been made by specialist departments of the Agricultural Development and Advisory Service (A.D.A.S.), Government research institutes and universities, though there has been little if any effort to collate the results. Examples of the more systematic studies in uncontaminated and contaminated areas include those reported by Williams & Rayner (1977), Davies & Roberts (1975), Colbourn & Thornton (1978) and Hughes (1979).

There are even fewer published data on regional variations in trace elements in pasture herbage and food crops, though general information has been reported by Williams (1963), Whitehead (1966), Archer (1971) and A.D.A.S. (1975).

Surveys of trace elements and metal contaminants in U.K. foods have been based on random samples of individual foodstuffs and the analysis of total diets (Hamilton & Minski 1972; Hubbard & Lindsay 1975). In this way the intake of Hg, Pb, Cd and As has been assessed (H.M.S.O. 1971, 1972, 1973). Surveys of this type do not provide information in sufficient regional detail to allow comparisons with estimations of human metal burden or with epidemiological data. Similarly, studies of Pb and Cd in fruit and vegetables (Thomas *et al.* 1972) and Se in food (Thorn *et al.* 1978) showed variations between the composition of different types of food rather than identifying geographic populations at risk.

Metals in surface waters have been monitored both at abstraction points and in the household, as the quality of potable supplies (the responsibility of the Regional Water Authorities) must meet standards set by the European Economic Community. For example, the present limit for Pb in surface waters for abstraction is 50 μg/l (E.E.C. 1975). A survey in Wales showed mean Pb concentrations of 1 μg/l in the waters of clean rivers, ranging up to 25 μg/l in those in regions containing old lead workings (Abdullah & Royle 1972). Pb may, of course, be dissolved from old plumbing systems, particularly by soft and acid waters, though a survey of public supplies in 1969 indicated that in most cases the Pb content complied with the International and European Standards of the World Health Organization of less than 100 μg/l (D.O.E. 1974). Concentrations of metals in surface waters may vary appreciably on both a diurnal and a seasonal basis in relation to rainfall, and it is difficult to make comparisons between surveys undertaken in different regions at different times with varying sampling and analytical techniques.

Elevated levels of metals in British coastal waters have been shown to be limited to estuarine and inshore waters affected mainly by industrial and domestic effluent and runoff from mineralized areas (Abdullah *et al.* 1972; Preston 1973). Anomalous metal loads in estuarine waters and sediments have been related to input from rivers draining base-metal mining areas (Hosking & Obial 1966; Elderfield *et al.* 1971; Thornton *et al.* 1975; Vivian & Massie 1977).

The available information on trace element and heavy metal levels in soils, crops and surface waters of the U.K. is generally insufficient in detail to provide the geographic patterns of distribution necessary for health studies on livestock or human populations. However, the need for trace element maps has in part been met by the geochemical reconnaissance surveys based on stream sediment sampling undertaken by the Applied Geochemistry Research Group (A.G.R.G.) at Imperial College and by the Institute of Geological Sciences (I.G.S.) (Webb *et al.* 1978; I.G.S. 1978*a*, *b*, 1979; Plant & Moore, this symposium).

Research by A.G.R.G. over the past 13 years into the interpretation and use of these maps in agriculture has confirmed relations between regional geochemical data and the known distribution of agricultural disorders, and has also indicated further suspect areas requiring detailed investigation (Webb 1964; Thornton & Webb 1970; Webb *et al.* 1971; Thomson *et al.* 1972; Jordan *et al.* 1975). These maps have delineated areas of low Co, Cu, Mn and Zn and high As, Cd, Cu, Pb, Zn, Ni, Cr and Mo. From a pollution viewpoint, these geochemical surveys have been shown to provide a useful catalogue of base-line information, related to the geochemistry of bedrock and soil parent materials; at the same time, the maps clearly show patterns reflecting metal contamination on a regional scale from past and present mining and smelting activities and from industrial and urban sources (Thornton 1975; Thornton & Webb 1975*a*).

Further applications have been demonstrated in the assessment of water quality (Aston *et al.* 1974; Thornton & Webb 1977). Knowledge of the chemical composition of the sediment can prove useful in predicting sites where, under certain conditions of rainfall and runoff, the metal load in associated waters may exceed medically recommended limits. In fact, sediment analysis may prove a more stable indication of metal excess than 'one-off' sampling of the waters, and at the same time helps to identify those metals that require regular monitoring.

Though investigations into possible relations between geochemistry and human health are as yet in their infancy in the U.K. it is considered that the geochemical atlas provides a unique source of multi-element data for siting food and medical surveys and also as a data bank for epidemiological studies. Application of the Geochemical Atlas of England and Wales to investigations of relations between geochemistry and crop, animal and human health are illustrated below.

Geochemistry and agriculture

The optimum range of most of the trace elements in soils is narrow, and serious deficiencies or excesses can result in crop failure or the death of grazing animals. Less severe imbalance may lead to reductions in crop yield or livestock production, sometimes without obvious visual symptoms in the plant or animal. These subclinical problems can be very extensive yet remain undetected and therefore untreated.

In the United Kingdom, disorders in crops and livestock related to trace element deficiencies or excesses are numerous and well documented. Many are, at least in part, geochemical in origin. Examples include:

(1) Cu deficiency in cereal crops, leading to a marked reduction in grain yield is associated with several geological formations, being recognized on a variety of soils derived from peaty, sandy and calcareous parent materials (Pizer *et al.* 1966; Caldwell 1971, 1976; Mitchell 1974; Reith 1975). Absolute Cu deficiency in cattle is occasionally reported on sandy soils. Amounts of total Cu in soils of England and Wales range from 2 μg/g on certain coarse-grained sandstones to 2000 μg/g in soils contaminated by mining (Thornton & Webb 1975*b*). A total soil Cu content of 2 μg/g or less has proved a useful indication of soils giving rise to deficiency in cereals (Purves & Ragg 1962), though problems are frequently found on soils with larger amounts of Cu where the metal is unavailable to the plant. EDTA-extractable Cu is widely used as a diagnostic aid for the identification of deficient soils in Britain (Pizer *et al.* 1966; Mitchell 1971).

The geochemical reconnaissance map for Cu (figure 1, plate 1) confirmed most of the known areas of absolute deficiency in England and Wales. Further low-Cu areas underlain by sandstones and sandstone-derived material were delineated where no crop deficiencies have been recognized as yet. Field trials with barley in some of these areas have shown responses to Cu application of up to 20% in grain yield even though visual deficiency symptoms were absent (Jordan *et al.* 1975).

(2) Co deficiency in sheep was first reported on soils derived from granites in southwest England (Patterson 1938). It is also commonly found on soils derived from sandstones, limestones, Silurian and Ordovician shales and acid igneous rocks in northern England and in Wales (Archer 1971) and on a variety of soils derived from acid igneous and arenaceous rocks in Scotland (Mitchell 1974). The total Co content of soils ranges from 1 to 100 μg/g and deficient herbage is usually found on soils containing 10 μg/g or less; a more reliable estimate of availability has been obtained by extraction with acetic acid (Mitchell 1971). Low Co patterns outlined by the geochemical atlas clearly define the granite outcrops in southwest England and many areas underlain by sandstone and sandstone drift; in some but not all of these areas unthriftiness in sheep has been reported. The atlas data indicate that marginal deficiencies in Co may be widespread and that many Co deficient areas are also potentially deficient in Cu.

(3) B deficiency, mainly in root crops, is recognized on a wide range of coarse-grained arenaceous parent materials (Batey 1971; Farrer 1976). The total B content of the soil is, however, of little use for diagnostic purposes as most of the B is present in the resistant mineral tourmaline, and is not available to plants.

(4) I deficiency in grazing livestock may lead to goitre, impaired fertility and loss of production. In general terms, sedimentary rocks contain more I than igneous rocks, and soils more I than the rocks from which they have developed, due to enrichment from marine sources. In Britain, however, there is no evidence that the I content of soils varies with distance from the

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DESCRIPTION OF PLATE 1

FIGURE 1. Map showing the distribution of Cu in stream sediments in England and Wales (compiled by the Applied Geochemistry Research Group as part of the *Wolfson geochemical atlas of England and Wales*); ppm, parts/10^6.

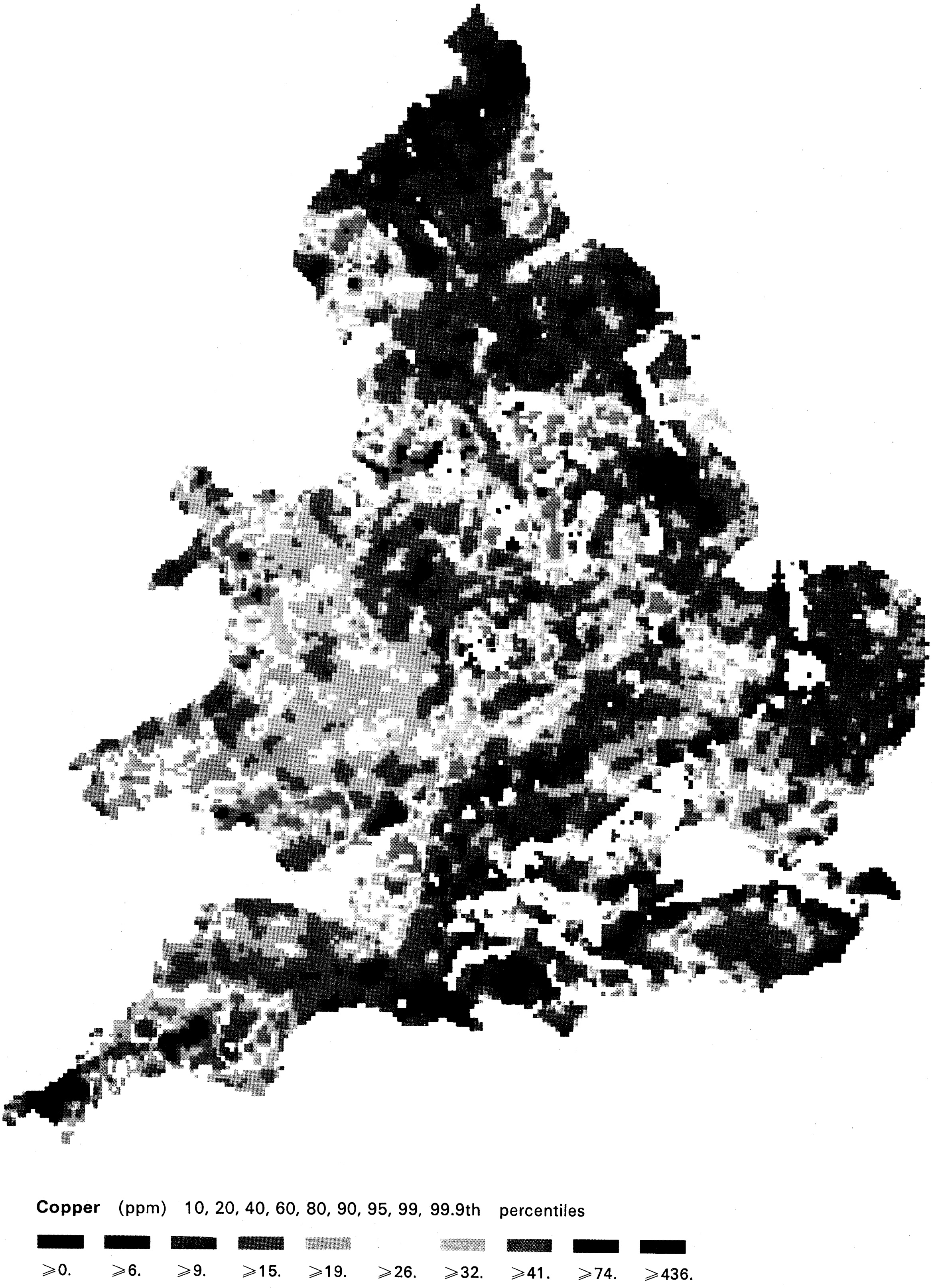

FIGURE 1. For description see opposite.

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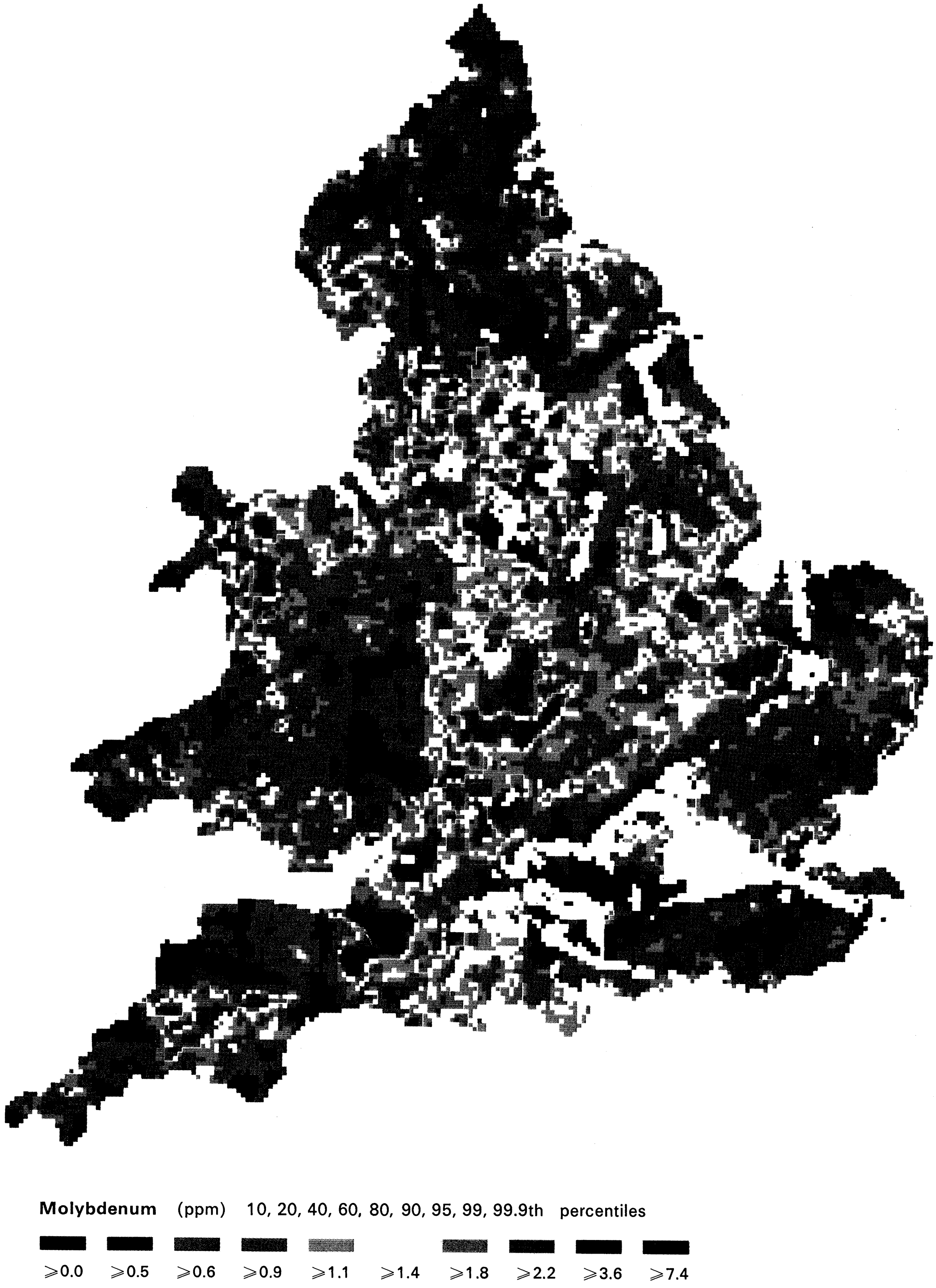

FIGURE 2. For description see opposite.

coast. The range of total I in soils from 23 sites in England, Wales and Scotland is wide (3–37 μg/g; Whitehead 1973) though no comparisons have been made on the basis of bedrock geology or parent material. Soils low in I usually produce plants low in I; it is of interest that all the herbage and hay samples collected by A.D.A.S. in southeast England and South Wales fell below the dietary requirement of 0.8 μg/g d.m. (dry matter) for cattle as specified by the Agricultural Research Council (Alderman 1968).

(5) Se deficiency giving rise to muscular dystrophy (white muscle disease) in grazing sheep and calves, has been recognized in several parts of England and Wales (A.D.A.S. 1975). A recent survey of blood glutathione peroxidase activity by the Central Veterinary Laboratory indicated that many of the 220 flocks of sheep tested in England and Wales were of low or marginal Se status (Anderson *et al.* 1979). No comparable data are available for rocks, soils or herbage. In Scotland, Se deficiencies in stock have been reported on light sandy soils and on soils developed from other arenaceous parent materials (Mitchell 1974); it is possible that sandy soils deficient in Cu and Co will also be deficient in Se.

TABLE 1. Se AND Mo CONTENT (micrograms per gram) OF SELECTED ROCKS AND OVERLYING POORLY DRAINED SOILS

(From Webb *et al.* 1966.)

		rocks		soils	
		Se	Mo	Se	Mo
North Staffordshire and Derbyshire	Lower Carboniferous				
	marine shales	2–24	10–30	1.5–7.0	8–45
	sandstone	2	15		
	limestone	0.2–1.0	<2		
Caernarvon	Ordovician				
	dark grey slates	0.7	4		
	black pyritic slates, upper bed	4.5–6.5	9–60	1.7–5.0	5–20
	black pyritic slates, lower bed	0.2–1.8	13–17		
Devon	Culm Measures				
	grey-black marine shales	<0.2–3.5	<2–15	0.2–4.0	10–20
	pyritic shales	2.5–6.0	15–30		
normal background				<0.2	<5

Geochemical studies have led to the recognition of Se-rich soils containing up to 7 μg Se/g in parts of central and southwest England and Wales underlain by marine black shale, which is also enriched in Mo (table 1). As yet no pastures growing on these soils have been found containing more than 1 μg Se/g d.m. and no problems have been recorded in livestock. Soils developed from similar black shale in Eire contain from 30 to over 300 μg Se/g and, under high pH or poorly drained organic soil conditions, may support herbage with 5–500 μg Se/g d.m. resulting in chronic selenosis in horses and cattle (Fleming & Walsh 1957; Fleming 1962).

DESCRIPTION OF PLATE 2

FIGURE 2. Map showing the distribution of Mo in stream sediments in England and Wales; ppm, parts/10^6.

Table 2. Range and mean Mo content (micrograms per gram) of stream sediment, rock, soil and herbage in four areas of England and Wales

(From Thomson *et al.* 1972.)

	Mo content†				
area and source rock	stream sediment	rock	soil (30–45 cm depth)	pasture herbage	bovine copper deficiency
Bowland Forest					
black shale (Bowland Shale)	3–60	13 <2–40 (26)	12 <2–85 (190)	2.9 0.8–7.2 (33)	recognized in part of area
other rocks (Carboniferous grey shales, limetsones and sandstones)	<2	<2 <2–2 (10)	<2 <2–4 (89)	0.9 0.7–1.0 (5)	
Shaftesbury					
black shale (Kimmeridge Clay and Oxford Clay)	3–13	12‡ (1)	4 <2–40 (105)	2.4 0.6–6.4 (35)	not recognized
other rocks (Jurassic calcareous clays, limestones and Cretaceous sandstones)	<2	<2 <2 (9)	<2 <2–5 (70)	0.7 0.2–2.4 (20)	
Bicester					
black shale (Oxford Clay)	3–8	5 2–14 (15)	3 <2–8 (33)	1.7 1.0–2.4 (8)	recognized in local districts; infertility reports
other rocks (Jurassic calcareous clays, limestones and boulder clay)	<2	<2 <2 (13)	<2 <2 (122)	0.7 0.1–1.3 (37)	
Meidrim					
black shale (Dicranograptus shales)	3–30	4 <2–7 (23)	7 <2–30 (66)	1.5 0.1–3.8 (32)	not recognized
other rocks (Ordovician grey shales, grits, flags)	<2	<2 <2 (13)	2 <2–5 (63)	0.9 0.3–2.6 (15)	

† Number of samples in parentheses.
‡ Kimmeridge Clay only: Oxford Clay not exposed.

(6) Mo toxicity in cattle was originally described on calcareous soils containing 20 µg Mo/g or more derived from the Lower Lias formation in Somerset (Ferguson *et al.* 1943; Lewis 1943; Le Riche 1959). It is now recognized that soils with 5 µg Mo/g may support herbage containing in excess of 2 µg Mo/g, which may in turn lead to scouring, loss of production and growth retardation in cattle due to reduced copper absorption and utilization. In England and Wales, soils derived from marine black shales ranging from Cambrian to Recent age contain from 1 to 100 µg Mo/g compared with the majority of soils developed from other parent materials which contain less than 2 µg Mo/g (Thomson *et al.* 1972; Thornton & Webb 1975*b*). The geochemical reconnaissance map for England and Wales (figure 2, plate 2) indicates the considerable extent of high Mo areas which are a potential hazard. In several of these geochemically defined areas, relations have been established between Mo in rock, stream sediment, soil and pasture, sometimes associated with clinical hypocuprosis in cattle (table 2).

In Derbyshire, Mo anomalies in stream sediment led to the recognition of areas totalling some 150 km² in which over 75% of the cattle were hypocupraemic but showed no clinical signs of hypocuprosis (Thornton *et al.* 1972). Subsequent Cu supplementation trials showed responses in live-weight gain in young cattle ranging from 14 to 32 kg per animal over a grazing season of 6 months. Herbage on these farms contained 3–12 μg Mo/g and 3–15 μg Cu/g d.m. Subclinical Cu deficiency in cattle is being increasingly reported elsewhere, though not always associated with excess Mo. A survey of some 20000 beef cattle on 1200 farms in Northern Ireland showed marked geographical trends in the distribution of herds with low Cu (Thompson & Todd 1976), in part corresponding with low Cu and high Mo areas mapped by a geochemical survey of the province (Webb *et al.* 1973).

The regional distribution of Mo may also contribute to the cause of swayback in sheep, as this disorder is frequently found on land within the geochemically defined high Mo patterns (Alloway 1973; Thornton & Alloway 1974).

The geochemical reconnaissance atlas has highlighted the principal mineralized areas in England and Wales where many agricultural soils are contaminated with one or more of the heavy metals Cu, Pb, Zn, Cd and As. Metalliferous mining in Britain began in Roman times or earlier and reached a peak in the latter part of the 19th century. Workings were extensive and smelters frequently located within or near the mines. Present-day metalliferous mining is

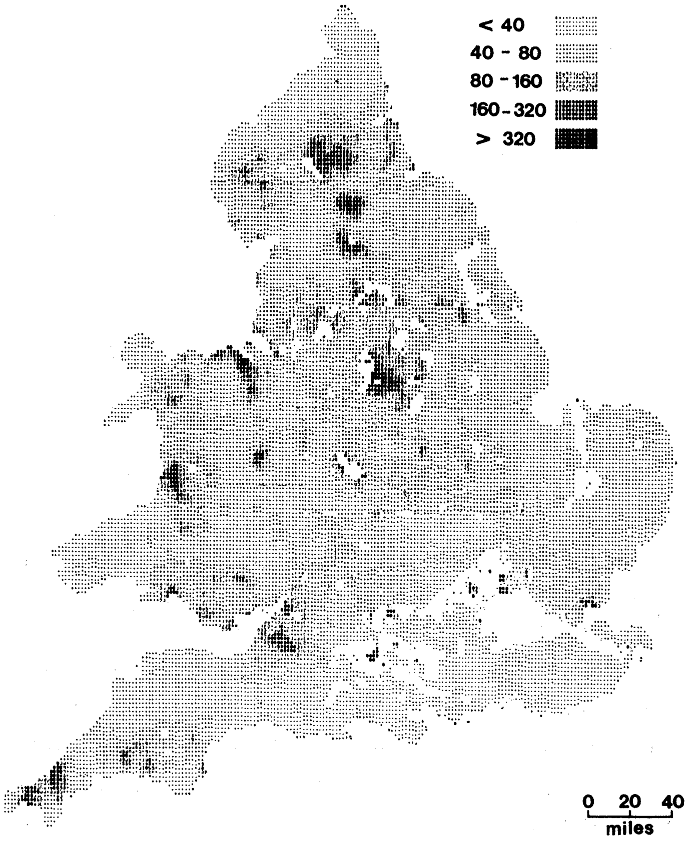

Figure 3. Map showing the distribution of Pb in stream sediments in England and Wales. Concentrations shown are in parts/10⁶.

far more restricted with three operational tin mines in Cornwall and lead produced as a by-product of the fluorspar industry in Derbyshire and the north Pennines.

Both upland and alluvial agricultural soils are heavily contaminated in the Tamar mining area of southwest England with peak values up to 2500 μg As/g and 2000 μg Cu/g, and similar contamination has been shown over some 250 km² in the west of the Cornish peninsula (Colbourn *et al.* 1975; Thornton 1977). There are frequently large variations in the metal content of soils on a local scale due to the variable influence of mine waste, dust, smelter fumes and underlying mineralized parent materials. In the mineralized area of 250 km² in Derbyshire, soils contain from several hundred to several thousand micrograms Pb per gram with up to 3% Pb close to old workings and smelters (Colbourn 1976). The normal range of Pb in uncontaminated U.K. soils is from 10 to 150 μg Pb/g.

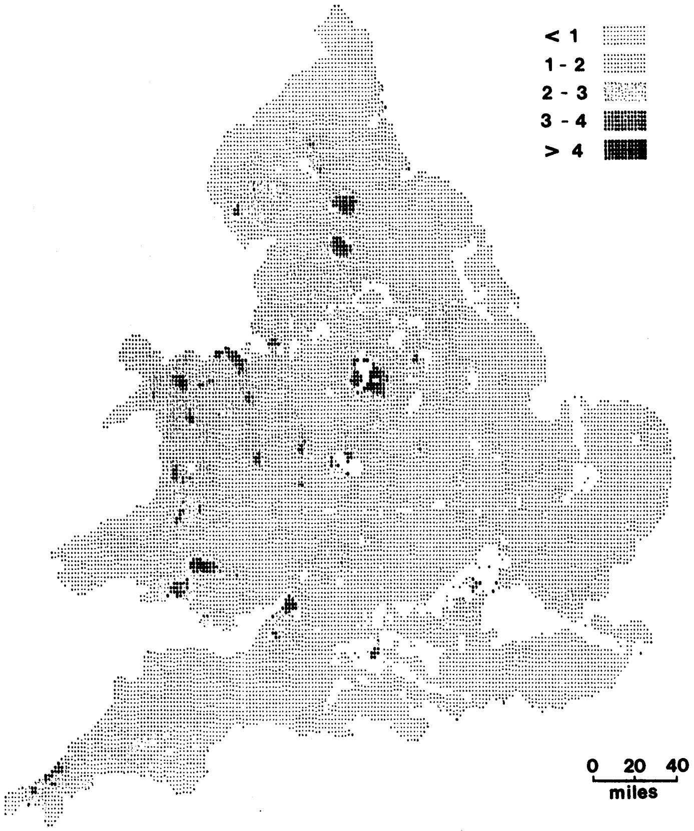

FIGURE 4. Map showing the distribution of Cd in stream sediments in England and Wales. Concentrations shown are in parts/10^6.

Both Cu and Zn toxicities have affected cereal crops on alluvium below old mines in southwest England and Wales. Lead poisoning in livestock in the vicinity of mines and smelters used to be fairly common at the height of industrial activity (Farey 1811; White 1842). More recently, Pb poisoning in calves and lameness and poor thriving in lambs have been noted in mining areas of the North Pennines (Stewart & Allcroft 1956; Harbourne & Watkinson 1968), and losses in lambs in north Derbyshire (Clegg & Rylands 1966). Clinical problems are now only rarely reported though there may well be subclinical effects on the health of livestock.

Blood Pb has been shown to reflect Pb levels in the soil, with herd means around 10 μg/100 ml blood on background farms with 100–200 μg/g in the soil, compared with 30 μg/100 ml or more on high-Pb farms in Derbyshire with 1000–2000 μg/g in the soil (Thornton & Kinniburgh 1978).

Multi-element deficiencies, toxicities and interactions

Associations between groups of several trace elements may well be of significance to crop and animal health. On parent materials derived from acid igneous rocks and arenaceous deposits, both soil and pasture contain potentially deficient amounts of one or more of the essential elements Cu, Co and Zn and sometimes Mn. In some areas the 'newer' essential elements Cr, Ni and V are also present in low amounts. It is suggested that combined deficiencies may occur, perhaps at a subclinical level, and should be investigated.

Marine black shales in Derbyshire, containing appreciable amounts of Mo, are also enriched in Se, Cd, Ni, V and Zn. Both Cd and Zn are known to influence the utilization of dietary Cu (Mills 1974) and these natural geochemical sources of the two elements may well interrelate with Mo and S in affecting the Cu status of grazing livestock.

As previously stated, soils in areas of base-metal mining and smelting are generally contaminated with two or more of the metals Pb, Zn, Cd, Cu, Sn and As, and possible synergistic or antagonistic effects need careful evaluation.

Factors influencing the rock–soil–plant–animal relation

The total trace element content of soil reflects to varying degrees that of the parent material, be it underlying bedrock or transported overburden; this can be modified by soil-forming processes such as gleying, leaching, podzolization and organic matter accumulation. These processes, together with soil pH, drainage and redox potential, influence the forms and mobility of trace elements in soils and their availability to plants. The soil–plant relation is also affected by plant species, stage of growth, season, and lime and fertilizer application. For example, in the U.K. mining areas, pasture herbage has been shown to reflect only to a small degree the extremely high metal contents of contaminated soils. It would seem that Pb, Cu and As in particular are either present in forms relatively unavailable for uptake by pasture species or that uptake and/or translocation are limited by regulatory processes within the plant. This is shown clearly by comparisons of As uptake by pasture on heavily contaminated land in the Tamar Valley, Cornwall, with that at control sites elsewhere (table 3). Marked seasonal effects on the Pb content of grass has been previously noted (Mitchell & Reith 1966); the practical significance of this variation is shown by comparisons between Pb-contaminated and control soils in Derbyshire, where herbage Pb contents are relatively low, irrespective of soil content, throughout the grazing season of cattle (figure 5).

The relation between trace elements in plants and amounts absorbed and utilized by the animal is affected by a variety of factors including the proportion of grass in the animal's diet, digestability of the diet and form and 'availability' of the ingested trace elements. Soil may also be an important source of trace elements to grazing cattle and sheep, which may involuntarily ingest up to 10% or more of their dry matter intake as soil under conditions in the U.K. (Field & Purves 1964; Thornton 1974). On contaminated soils, such as those in southwest England where the soil contains up to 2500 μg As/g and herbage rarely 25 μg/g, cattle and sheep may ingest up to ten times the amount of the element in the form of soil to that in herbage.

TABLE 3. RANGE AND MEAN As CONTENTS (micrograms per gram) OF SOIL AND HERBAGE (APRIL CUT, D.M.) AT SELECTED LOCATIONS NEAR THE RIVER TAMAR, MIDHURST, HALKYN AND SOUTHEND

site	no. of samples	soil As	herbage As
Tamar	23	23–1080 228	0.26–9.60 2.84
Midhurst	13	9–33 16	0.20–1.86 0.50
Halkyn	14	9–26 16	0.33–1.29 0.63
Southend	10	7–12 9	0.25–0.67 0.43

Determined by hydride generation and atomic absorption spectrophotometry with electrothermal atomization after digestion with nitric and sulphuric acids (Thompson & Thoresby 1977).

Soil ingestion may also be an important geochemical pathway for those nutritionally important elements such as Co, Cr and Se with a relatively high soil : herbage ratio. However, there is little information on the availability to the animal of trace elements ingested as soil; in fact it has been shown that ingested soil may actually reduce the availability of Cu fed to sheep (Suttle *et al.* 1975). The soil–animal relation may thus complement and at times override that of the soil–plant–animal and, as such, constitutes a far closer contact between the animal and its geochemical environment than the pathway involving the plant.

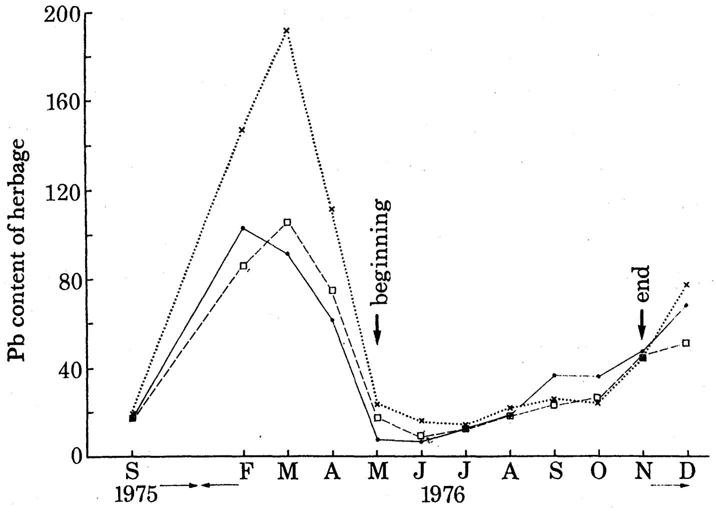

FIGURE 5. Seasonal variations in the Pb contents (parts/10^6 d.m.) of pasture herbage growing in contaminated and uncontaminated soils in Derbyshire. Arrows mark the beginning and end of the grazing season. □, Low soil Pb (100–200 parts/10^6); •, medium soil Pb (600–800 parts/10^6); ×, high soil Pb (1000–2000 parts/10^6).

GEOCHEMISTRY AND HUMAN HEALTH

Geochemical surveys have highlighted a number of anomalous situations that in part contribute towards the metal burden of man through foodstuffs, drinking water and the atmosphere.

(*a*) *Food crops.* In areas contaminated by metalliferous mining and smelting, the low availability of metal contaminants to grass is on the whole mirrored by low uptake by crops. For instance, only small amounts of Pb, Zn and Cd were taken up by *Brassica* crops growing in calcareous garden soils containing 1% or more Pb in Derbyshire (Thornton & Webb 1973). In mining areas of southwest England and north Wales, edible tissues of barley, lettuce and strawberries showed only small increases in Cu, Pb and As content compared with those sampled at control sites. In the Tamar mining area, on soils ranging from 20 to 300 μg As/g, the As content of barley grain increased with soil content, but in no case contained more than 0.4 μg/g d.m. (Thoresby & Thornton 1979). Moderate increases in the content of Pb and other metals in salad and root crops have been reported on soils contaminated by mining and smelting (Warren *et al.* 1967; Alloway & Davies 1971; Davies 1973; Davies & Roberts 1975) and this pathway of potentially toxic metals into the human must not be ignored, especially in local communities producing home-grown vegetables. It has been suggested that cereal and vegetable food crops are likely to contribute as much as 70% of the overall dietary intake of Cd (Lindsay 1979); in particular, Cd from metal-rich sewage sludge may at times enter the food chain.

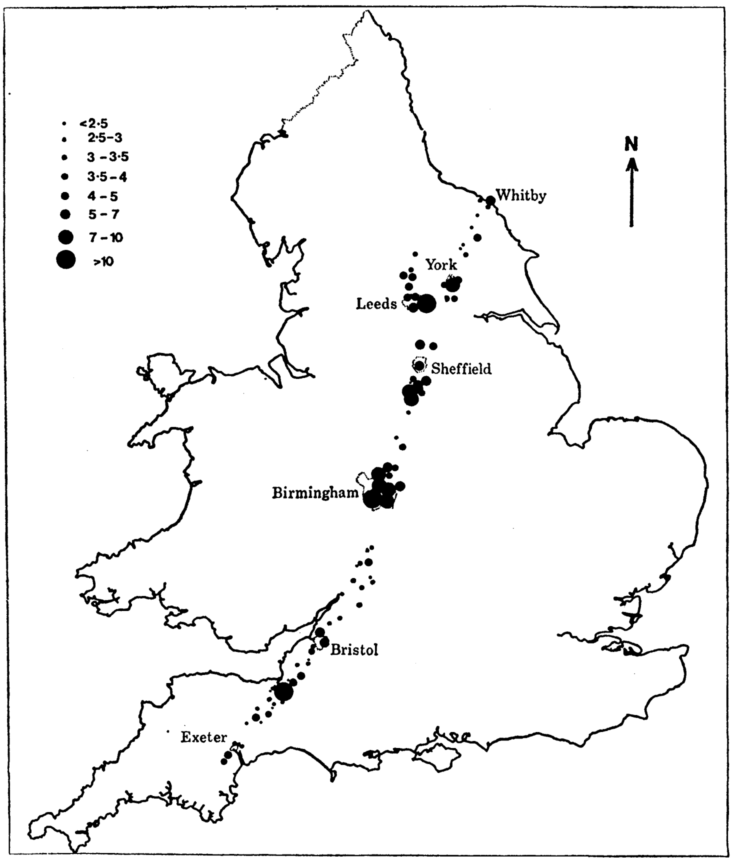

FIGURE 6. Annual deposition of Pb in rainfall (circles indicate total soluble Pb in micrograms per square centimetre per year).

(*b*) *Water supplies.* As indicated previously, geochemical mapping can be used in assessing regional differences in water quality, though contamination of rivers by industrial and sewage effluents and of household supplies by lead piping and other materials are of paramount concern. Moreover, surface waters draining mineralized areas, particularly when associated with waste materials, nearly always reflect metal input from these sources (Thornton & Webb, 1975*a*) and must be carefully monitored if used for abstraction of potable supplies.

(*c*) *Metals in dust and air*. Elevated levels of metals in road and house dust have been recorded in a number of *ad hoc* studies, with, for instance, several thousand micrograms Pb per gram recorded in dusts from Birmingham streets and buildings (Stephens 1975) and up to 5000 μg Pb/g or more in house dusts in old Derbyshire mining villages (Barltrop *et al.* 1975). The contribution from inhaled dusts has not been evaluated, though it could be significant in contaminated environments.

There is little information on regional differences in the composition of airborne particulates, though measurements of total and dry deposition reported by Peirson & Cawse (this symposium) and of minerals and trace elements in rainfall (Wadsworth & Webber 1979) give clear indications that geographical differences do occur. A recent survey undertaken by A.G.R.G., based on the collection of composite annual rainfall samples at 100 locations on a traverse from southwest to northeast England, showed patterns of metal enhancement in industrial and heavily populated areas (figure 6).

(*d*) *Other sources*. In general, metals do not accumulate in dairy products or edible animal tissues, with the exception of liver and kidney. Shellfish in estuarine waters may accumulate metals though these are unlikely to form a significant part of the diet of even the local community.

Epidemiological studies in the United Kingdom

Although there is strong evidence linking the distribution of trace elements in the environment and the prevalence of certain human diseases, actual causal relations in Britain are few.

(*a*) *Iodine*. Endemic goitre in man is associated primarily with a deficiency of I in water supplies and food. At one time common in parts of Britain, its prevalence has considerably diminished over the past 100 years with rising standards in hygiene, better food, improved water supplies and more recently the introduction of iodized table salt (Kelly & Snedden 1960). However, the problem is by no means resolved. For example, in some villages in Somerset the goitre incidence was reported as 56% where drinking water averaged 2.9 μg I/l compared with 3% in villages with waters containing 8.2 μg I/l (Young *et al.* 1936). A high incidence has been reported in south Wales (Davies & Rogers 1940) and, more recently, high rates in schoolchildren in part of north Oxfordshire associated with a belt of limestone and marl (Hughes *et al.* 1958). It has been suggested that the prevalence of goitre is higher in areas with hard waters.

(*b*) *Fluorine*. A close inverse relationship has been established in many parts of the world between the incidence of dental caries and the fluoride content of the water supply (Underwood 1977). The first connection between fluoride in waters and dental decay in the United Kingdom resulted from observations of dental mottling in people drinking soft waters of high fluoride content (4.5–5.5 mg F/l) from deep wells in the Reading Beds and Thanet Sands near Maldon, Essex (Ainsworth 1933). The mottling was associated with a low incidence of caries in permanent teeth. Comparisons between children in South Shields and North Shields showed lower caries incidence in the former with a water supply containing 1.2–1.8 mg F/l derived from deep wells in the Magnesian Limestone than in the latter with water containing less than

0.25 mg F/l largely from a peaty moorland catchment (Weaver 1944). More recently, markedly lower caries has been shown in adults in Hartlepool with a naturally high fluoride water (1.5–2.0 mg F/l) compared with those in York with a low fluoride water supply (0.15–0.28 mg F/l) (Murray 1971). It has now been repeatedly established in both children and adults that consumption of water containing 1 mg F/l or more over the years of tooth formation substantially lowers the prevalence of dental caries; where appropriate, addition of fluoride to this level is recommended (Royal College of Physicians 1976).

(*c*) *Empirical relations.* The prevalence of cardiovascular disease has been negatively correlated with water hardness in 61 large county boroughs of England and Wales with populations over 80000 (Crawford *et al.* 1968). Higher levels of Pb were found in ribs from three soft-water towns compared with three hard-water towns, though this may well be due to the effects of Ca on Pb absorption rather than to plumbosolvency or geochemical factors (Crawford & Clayton 1973). Epidemiological studies on cardiovascular diseases are continuing (see papers by Shaper and Masironi in this volume).

An abnormal distribution of cancer in several villages in southwest England (Allen-Price 1960) has led to a number of studies on trace metals in mineralized and neighbouring areas (Pinsent 1968; Davies 1973). However, large amounts of As and heavy metals in stream sediments and soils in parts of the area examined did not provide clearcut geochemical differences between high cancer and control villages. The incidence of stomach cancer in north Wales has been positively correlated with the Zn : Cu ratio in garden soils (Stocks & Davies 1964). The Royal College of General Practitioners is currently funding a reconnaissance survey recording morbidity data in 60 practices for comparison with environmental data from published sources, including that comprising the Geochemical Atlas of England and Wales (B. E. Davies, personal communication).

Variations in the prevalence of dental caries have been recorded between the high Mo ‘teart’ area on the Lower Lias formation in southwest England (on which molybdenosis is recognized in grazing cattle) and nearby control areas, though differences in the composition of drinking water, 3 μg Mo/l in the former compared with 1.8 μg/l in the latter, were not considered sufficient to account for the caries incidence (Anderson 1969). In the mineralized Tamar Valley in southwest England, children 12 years old living on the Bere Peninsula had a raised caries level compared with those of similar age in other parts of southwest England (Anderson *et al.* 1976). It has been suggested that this increase in caries prevalence is related to extensive soil contamination with Pb. Similar studies in Cardiganshire [now part of Dyfed], Wales, have confirmed high caries prevalence in areas of historical lead mining (B. E. Davies, personal communication).

PUBLIC HEALTH

The Geochemical Atlas of England and Wales was used to select areas in which to compare Pb burdens of children 2–4 years old residing in villages contaminated by past mining and in control villages in Derbyshire. A collaborative study by the Paediatric Unit, St Mary's Hospital Medical School, and A.G.R.G. showed that, when households were grouped according to the Pb content of their garden soils, Pb in children's blood and hair increased with that in soil and house dust. However, none of the Pb values in children were high enough to be considered hazardous at that time, even though the amounts in soil and dust were extremely high, peaking at 2.8 and 2.5% Pb respectively (Barltrop *et al.* 1975). The childrens' Pb status does, however, reflect that of the environment and, in the absence of evidence linking the human burden with Pb in foodstuffs or water supplies, it was suggested that the major pathway of Pb into the children is through inhalation and involuntary ingestion of dust particles (Barltrop *et al.* 1975).

Conclusions

Relations between geology, the trace element status of parent materials and soils, and deficiency and excess in crops and livestock are well documented in the U.K. Areas in which marginal trace element imbalance may result in subclinical problems affecting agricultural production are less well defined and may be widespread. There are few systematic data showing regional differences in trace element levels in rocks, soils, food crops, surface waters and airborne materials suitable for comparison with information on crop, animal and human health. The need for trace element maps has been met in part by regional geochemical reconnaissance surveys, based on stream sediment sampling, undertaken by A.G.R.G. in England, Wales and Northern Ireland and I.G.S. in Scotland, England and Wales. These maps have been usefully applied to a number of problems in agriculture, and have focused attention on several areas in which food crops and surface waters contain amounts of heavy metals above normal. They have also been used in the selection of Pb-rich areas for studies on the human population. Interpretation of geochemical reconnaissance data is by no means straightforward and their application to agricultural and human problems should therefore be conducted in consultation or preferably collaboration with geochemists with an understanding of their uses and limitations. Provided this is the case, geochemical atlases will continue to provide a unique source of multi-element data for area selection in food, water and medical surveys, particularly in rural districts.

It is essential, however, that future research be aimed at providing reliable baseline data showing regional and local differences in the chemical composition of foodstuffs and drinking waters in relation to the geochemical environment. Similarly, there is little information on (*a*) the relative contribution of local sources of trace elements or major nutrients to the diet, and (*b*) variations in dietary habits between different geographical, ethnic and socio-economic communities. In particular, in polluted environments there is a requirement for studies into the pathways by which metals enter the body, and their forms and absorption. Finally, there is an urgent need for the collection of morbidity and mortality data on a systematic local basis rather than for administrative regions whose boundaries are unlikely to correspond to geochemical patterns. Until reliable epidemiological information is available, it will not be possible to assess the full potential of relations between geochemistry and human health in the U.K.

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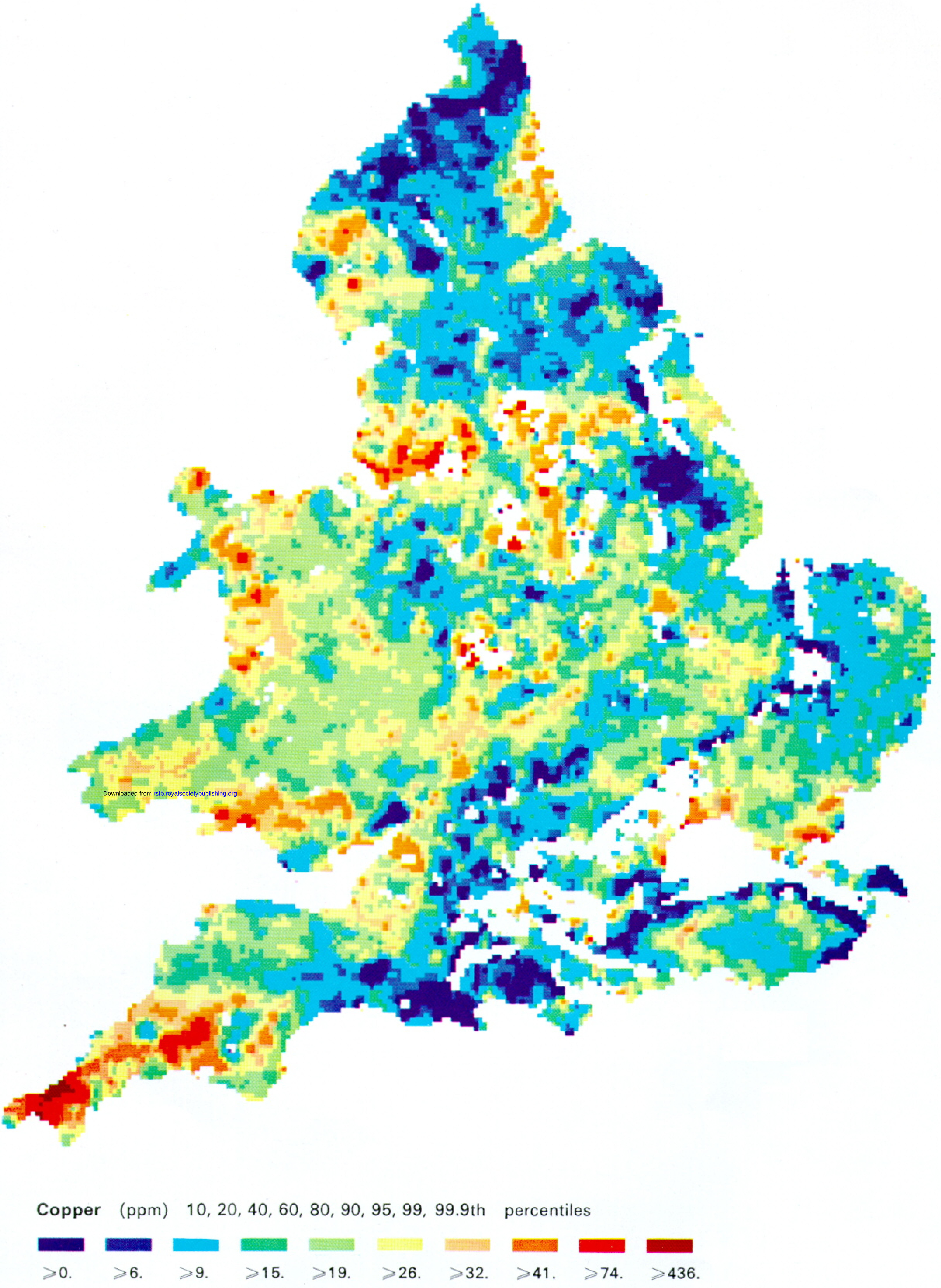

FIGURE 1. For description see opposite.

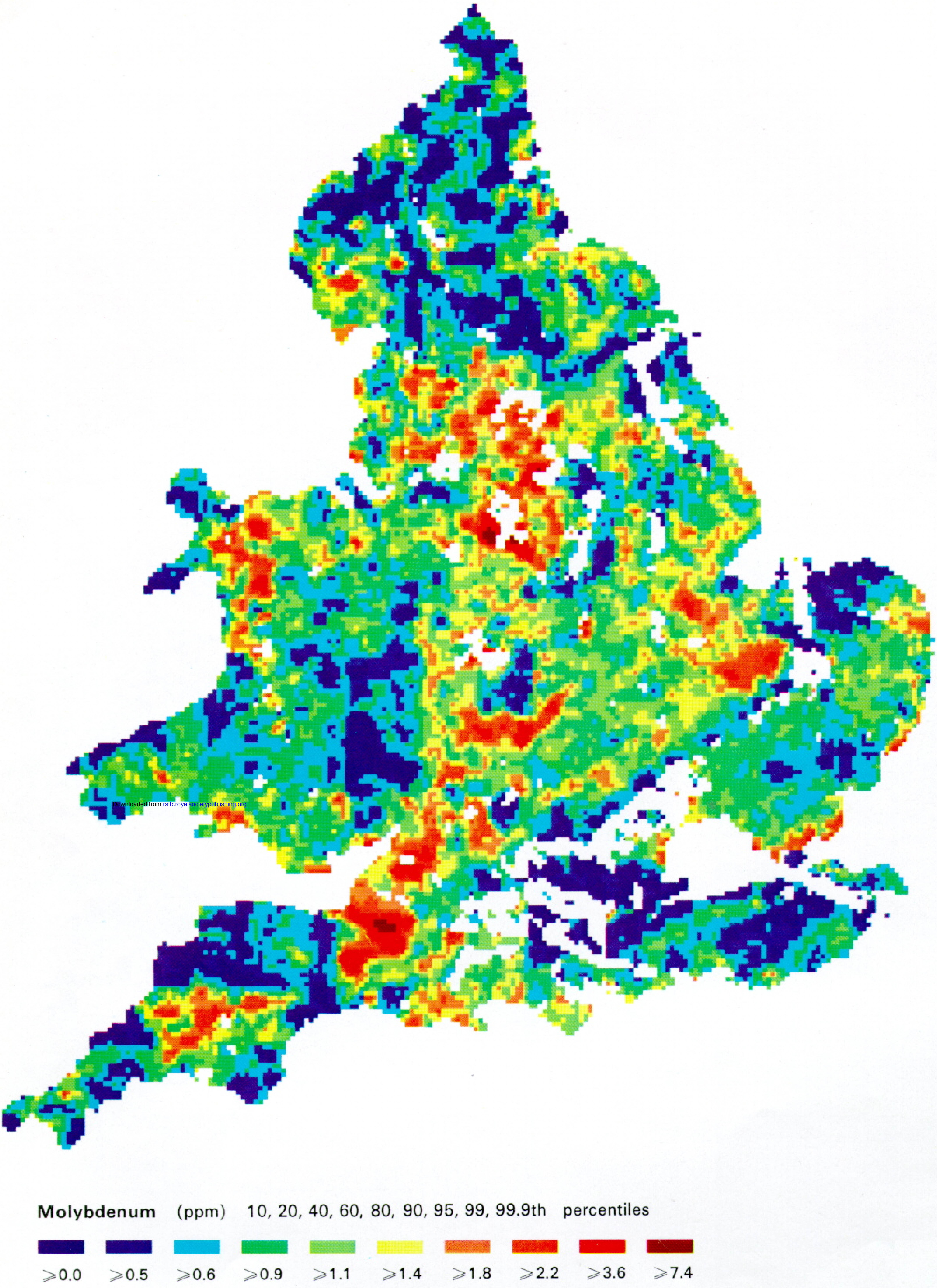

FIGURE 2. For description see opposite.